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ALTERNATING-CURRENT NETS

BY ARTHUR E. KENNELLY

ALTERNATING-CURRENT NETS

BY ARTHUR E. KENNELLY

Communicated 13th March 1929

Purpose and Scope

It is the purpose of this paper to show that every network or *net* of conducting elements, in the steady state, operated between a pair of input- and a pair of output-terminals, at a single impressed frequency, including zero frequency or continuous current as the simplest case, is replacable by two pairs of T's and Π's, called respectively the *basic* and the *alternative* pair. In the continuous-current case, the T and Π of the alternative class have arithmetical significance only, and are physically unrealisable; but in alternating-current cases this distinction may fail. Realisability may attach to either or both classes. In simple alternating-current transformers, neither class fails.

A three-terminal alternating-current net corresponds to a particular family of plane triangles, a property that had previously been apparently limited to continuous-current cases, or to especially simple alternating-current cases.

Continuous-Current Four-Terminal Nets

In any net, such as the rectangular net in Fig. 1, with 24 resistance elements, input terminals ag, and output terminals bh, it is known that the angle θ of the net between these pairs of terminals is defined by either of the two equations:

$$\tanh\,\theta = \sqrt{\frac{R_{ag}}{R_{af}}} = \sqrt{\frac{R_{bg}}{R_{bf}}} \qquad \text{numeric } \angle \qquad (1)$$

where R_{af} and R_{ag} are the net resistances measured at terminals ag, with the bh terminals respectively opened and shorted, and similarly for the resistances R_{bf} and R_{bg} at the bh terminals.

In the simple example of Fig. 1, the net reduces to the six-element structure in the lower part of the diagram, AG, BH, for which

$$\tanh^2\theta = \frac{2428.57}{6000} = \frac{2833.\dot{3}}{7000} = 0.40476 \qquad (2)$$

or

$$\tanh\,\theta = 0.636209 \qquad (3)$$

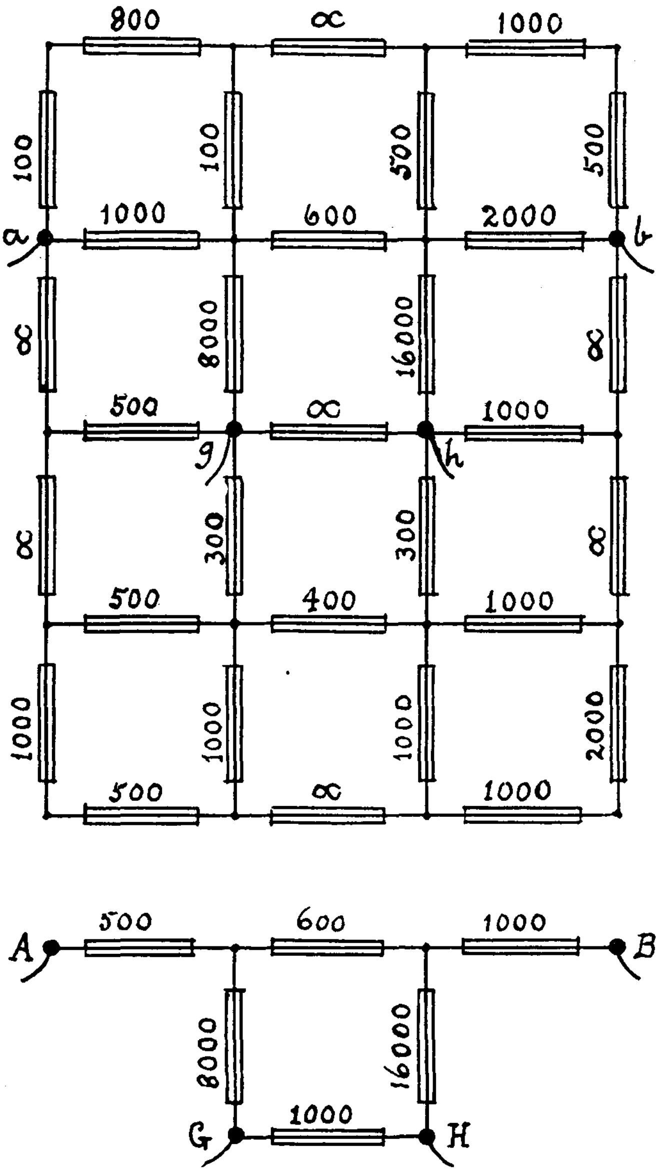

800
∞
1000
100
100
500
500
1000
600
2000
a
b
∞
8000
16000
∞
500
∞
1000
g
h
∞
300
300
∞
500
400
1000
1000
1000
1000
2000
500
∞
1000
A
500
600
1000
B
8000
16000
1000
G
H

FIGURE 1. Particular Rectangular D. C. Net and its Simplified Counterpart.

The ordinary solution or *basic solution* of (3), by the use of Tables of real hyperbolic functions, is:

$$\theta = 0.751779 \text{ hyperbolic radian, or hyp.} \tag{4}$$

which is the net angle for continuous currents, and these particular pairs of terminals. There is, however, another solution for (3), which may be called the *alternative solution;* namely,

$$\theta = 0.751779 \pm j\pi = 0.751779 \pm j\underline{2} \quad \text{hyps.} \angle \tag{5}$$

That is, we may add or subtract $j\pi$ hyp. radians or π circular radians ($\underline{2}$ circular quadrants) to the angle θ, without altering its tangent, since $\tanh\theta$ is a periodic function of period $j\pi$. This alternative solution of (3) is here the subject of discussion, especially in relation to alternating-current nets.

Table I presents the principal functions of the two values of θ.

TABLE I

Basic	Alternative
$\theta = 0.751779$ $\sinh\theta = 0.824621$ $\cosh\theta = 1.296148$ $\tanh\theta = 0.636209$	$\theta = 0.751779 \pm j\underline{2}$ $\sinh\theta = -0.824621$ $\cosh\theta = -1.296148$ $\tanh\theta = 0.636209$

It is evident that adding or subtracting $j\underline{2}$ from θ, changes the sign of both the sine and the cosine; but leaves the tangent unaltered.

Alternative Equivalent Circuits corresponding to the two Values of θ

It is known that if we define the surge impedances of the net z_{oa}, z_{ob}, at each end, as the vector geometrical mean of the measured values R_f and R_g, we have:

$$z_{oa} = \sqrt{R_{ag}\cdot R_{af}} = \sqrt{2428\cdot57 \times 6000} = 3817\cdot26 \text{ ohms} \tag{6}$$

$$z_{ob} = \sqrt{R_{bg}\cdot R_{bf}} = \sqrt{2833\cdot33 \times 7000} = 4453\cdot46 \text{ ohms} \tag{7}$$

also the geomean surge impedance becomes

$$z_{ab} = \sqrt{z_{oa}\cdot z_{ob}} = \sqrt{3817\cdot26 \times 4453\cdot46} = 4123\cdot11 \text{ ohms} \tag{8}$$

or

$$y_{ab} = 1/z_{ab} = 0.242535 \times 10^{-3} \text{ mho.} \tag{9}$$

Duplicate Equivalent T's

We proceed to form the duplicate equivalent T's of the net in Fig. 1, in the manner indicated by Figs. 2 and 3. The rule, in all cases, is to place in the staff of the equivalent T an admittance of $y_{ab} \cdot \sinh \theta$ mhos. According to Table I, there are two values for $\sinh \theta$ in this example; namely, 0.824621 and $-$ 0.824621. There are thus two duplicate values for the staff admittance, differing in sign; namely 0.2×10^{-3} and -0.2×10^{-3} mho, corresponding to 5000 and $-$ 5000 ohms respectively. These duplicate values appear in Figs. 2A and 2B.

There is of course no arithmetical difficulty in employing at o' o, Fig. 2B, a negative resistance of $-$ 5000 ohms; but physically, the concept is meaningless, in the absence of generative apparatus or electric source in the staff. We are therefore physically prevented from using the alternative solution (3) and the equivalent T pertaining to the same; but since we shall find that the alternative solution is arithmetically valid, we may proceed to complete it, for subsequent extension to alternating-current cases.

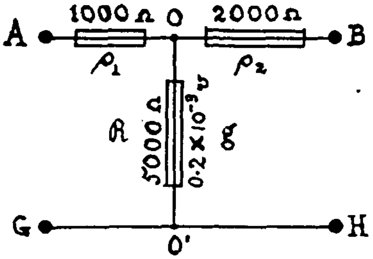


FIGURE 2A. Basic Equivalent T.

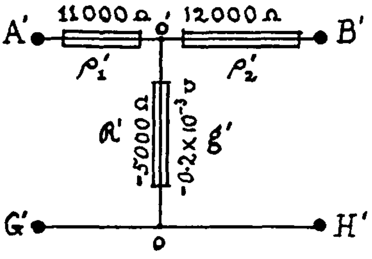


FIGURE 2B. Alternative Equivalent T.

Completing the duplicate T's so as to comply with the measured values $R_{af} = 6000$ and $R_{bf} = 7000$ ohms, we have in Fig. 2A, $\rho'_1 = Ao = 1000$ and $\rho_2 = oB = 2000$ ohms; while in Fig. 2B, $\rho'_1 = A'o = 11000$ and $\rho'_2 = o'B' = 12000$ ohms. It will be observed that

$$\rho_2 - \rho_1 = \rho'_2 - \rho'_1 \qquad \text{ohms} \angle \qquad (10)$$

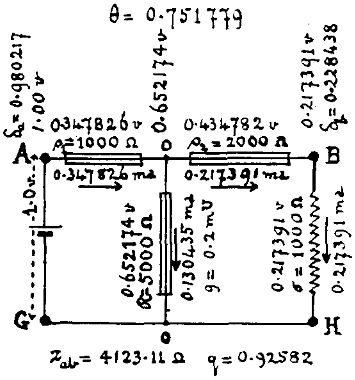
or the arm differences are the same in both T's. It will then be found that the two T's are arithmetically equivalent. That is, either can be used to replace the net of Fig. 1 between terminals AG and BH, with any assigned external sources or loads.

Comparative Behavior of the Basic and Alternative T's

The effect of changing from the basic to the equivalent T is to reverse the polarity or direction of voltage and current at output terminals, leaving their product, the output power, unchanged in sign. Thus, in Figs. 3A and 3B, an emf. of 1.0 volt is impressed at input terminals and a load of $\sigma = 1000$ ohms is connected to the output terminals. In the basic T, the output emf. is 0.217391 volt and the output current 0.217391 milliampere. In the alternative T, these values have the negative sign, or the opposite direction. The effect in the load σ is such as might be produced by reversing the output terminals.

Again, if we examine the position angles at output and input terminals in the two cases, we have the position angle δ_b at BH, from the known relation:

$$\delta_b = \tanh^{-1}\left(\frac{\sigma}{z_{ob}}\right) \qquad \text{hyps } \angle \qquad (11)$$


θ = 0·751779
δ_a = 0·980217
1·00 v
0·347826 v
0·652174 v
0·434782 v
0·217391 v
δ_b = 0·228438
ρ_1 = 1000 Ω
O
ρ_2 = 2000 Ω
A
B
0·347826 mA
0·217391 mA
1·0 v.
0·652174 v
R_3 = 5000 Ω
0·130435 mA
g = 0·2 m℧
0·217391 v
σ = 1000 Ω
0·217391 mA
G
H
O
z_{ab} = 4123·11 Ω
q = 0·92582

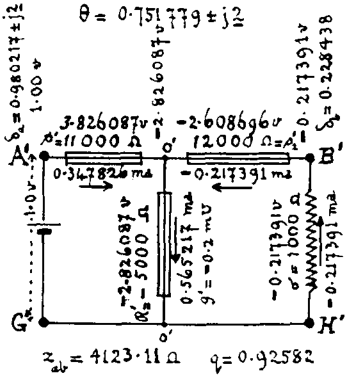

θ = 0·751779 ± j2
δ_a = 0·980217 ± j2
1·00 v
3·826087 v
−2·826087 v
−2·608696 v
−0·217391 v
δ_b = 0·228438
ρ_1' = 11000 Ω
O'
12000 Ω = ρ_2'
A'
B'
0·347826 mA
−0·217391 mA
1·0 v
−2·826087 v
R_3' = −5000 Ω
0·565217 mA
g' = −0·2 m℧
−0·217391 v
σ = 1000 Ω
−0·217391 mA
G'
H'
O'
z_{ab} = 4123·11 Ω
q = 0·92582

FIGURE 3A. Basic Equivalent T. FIGURE 3B. Alternative Equivalent T.
Load of 1000 ohms at BH, and 1.0 volt impressed at AG.

This applies to both the basic and alternative T; but the position angle δ_a, at AG, which is always $\theta + \delta_b$, is different in the two cases. It is 0.980217 in Fig. 3A, and $0.980217 \pm j\underline{2}$ in Fig. 3B. The sine and cosine of the latter angle will both be essentially negative. Consequently the equations for output voltage and current:

$$E_b = \frac{E_a}{q} \cdot \frac{\sinh \delta_b}{\sinh \delta_a} \qquad \text{volts } \angle \qquad (12)$$

and

$$I_b = I_a q \frac{\cosh \delta_b}{\cosh \delta_a} \qquad \text{amperes} \angle \qquad (13)$$

must give positive continuous-current values with the basic T and negative values with the alternative T.

Duplicate Equivalent Π's.

If we insert in the architrave of the equivalent Π, according to regular rule, the impedance

$$\rho = z_{ab} \sinh \theta \qquad \text{ohms} \angle \qquad (14)$$

there will be two duplicate Π's, using the two values of sinh θ from Table I. These are represented in Figs. 4 and 5. In *AB*, we insert

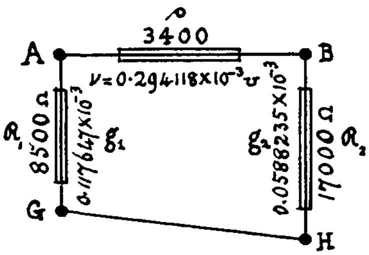

ρ
3400
A
B
ν=0·294118×10⁻³℧
R₁
8500 Ω
0.117647×10⁻³
g₁
g₂
0.0588235×10⁻³
17000 Ω
R₂
G
H

FIGURE 4. Basic Equivalent Π.

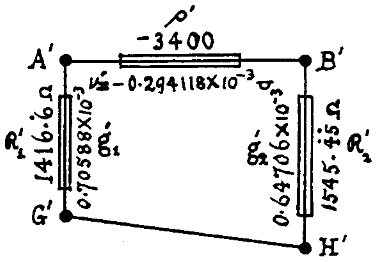

ρ′
-3400
A′
B′
ν′=-0·294118×10⁻³℧
R′₁
1416.6 Ω
0.70588×10⁻³
g′₁
g′₂
0.64706×10⁻³
1545.45 Ω
R′₂
G′
H′

FIGURE 5. Alternative Equivalent Π.

4123.11 × 0.824621 = 3400 ohms; while in *A′B′*, we insert arithmetically the negative of this, or −3400 ohms. The pillar leaks must then be selected such that

$$g_1 + \nu = G_{ag} = \frac{1}{R_{ag}} \qquad \text{mhos} \angle \qquad (15)$$

and

$$g_2 + \nu = G_{bg} = \frac{1}{R_{bg}} \qquad \text{mhos} \angle \qquad (16)$$

Here again, the duplicate equivalent Π's are equally valid arithmetically; but the alternative Π, with its negative resistance architrave is physically meaningless and unrealisable, in the absence of some generating device.

There are thus four three-element equivalent structures which arithmetically simulate the behavior of a given four-terminal net.

of which two only are physically realisable in the continuous-current case. The effect of changing from the basic to the alternative structures, is to reverse the direction of voltage and current at output terminals.

Alternating-Current Nets

Every single-frequency alternating-current net, in the steady state, whose elements individually obey alternating-current Ohm's law,* is known to subtend a complex angle $\theta = \theta_1 + j\theta_2$, as defined by formula (1); where the measurable impedances R_{af}, R_{ag}, R_{bf} and R_{bg}, are all complex quantities. As, in the continuous-current case, equation (1) admits of two solutions, one basic and the other alternative, and the latter value of θ differs from the former by $\pm\ \pi$ in the imaginary component; i. e. 2 quadrants, 200 grads, or 180 degrees

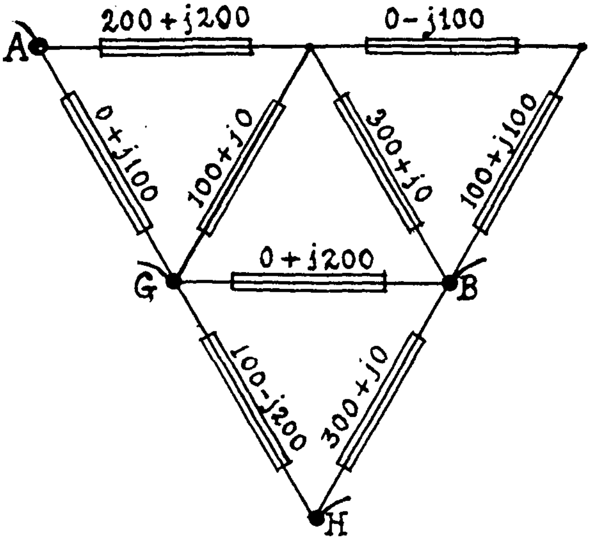


Figure 6. Particular Nine-element A. C. Net.

Thus, the particular nine-element net of Fig. 6, gives rise to the relations: $R_{ag} = 84{\cdot}070 \angle 78^\circ\,47'\,55''$

$$R_{bg} = 134{\cdot}063\ \overline{\diagdown}\ 19^\circ\,12'\,41'' \quad \text{ohms} \angle \qquad (17)$$

---

* Bibliography 1a.

$$R_{af} = 83 \cdot 5417 \angle 79^\circ\, 13'\, 56''$$

$$R_{bf} = 133 \cdot 220 \;\overline{\diagdown}\; 18^\circ\, 46'\, 40'' \quad \text{ohms} \angle \qquad (18)$$

The ratio of either of these pairs of terminal impedances gives, following (2) and (3),

$$\tanh^2 \theta = 1 \cdot 00632 \;\overline{\diagdown}\; 0^\circ\, 26'\, 1'' \quad \text{numeric} \angle \qquad (19)$$

and

$$\tanh \theta = 1 \cdot 00316 \;\overline{\diagdown}\; 0^\circ\, 13'\, 0.5'' \quad \text{numeric} \angle \qquad (20)$$

The basic solution of this, by Tables or Charts,* is

$$\theta = 3 \cdot 003 + j2 \cdot 007 = 3 \cdot 003 + j\underline{1 \cdot 279} \quad \text{hyps} \angle \qquad (21)$$

and the alternative solution is

$$\theta = 3 \cdot 003 - j1 \cdot 135 = 3 \cdot 003 - j\underline{0 \cdot 721} \quad \text{hyps} \angle \qquad (22)$$

Table II gives the principal functions of θ for the two cases.

TABLE II

	Basic	Alternative
θ	$3.003 + j\,\underline{1.279}$	$3.003 - j\,\underline{0.721}$
$\sinh \theta$	$10.0924 \angle 114^\circ\, 59'\, 51''$	$-10.0924 \angle 114^\circ\, 59'\, 51''$ or $10.0924 \;\overline{\diagdown}\; 65^\circ\, 0'\, 9''$
$\cosh \theta$	$10.0607 \angle 115^\circ\, 12'\, 52''$	$-10.0607 \angle 115^\circ\, 12'\, 52''$ or $10.0607 \;\overline{\diagdown}\; 64^\circ\, 47'\, 8''$
$\tanh \theta$	$1.00316 \;\overline{\diagdown}\; 0^\circ\, 13'\, 1''$	$1.00316 \;\overline{\diagdown}\; 0^\circ\, 13'\, 1''$

If we take the basic form, the staff admittance for the equivalent T is $y_{ab} \sinh \theta = 9.44921 \times 10^{-3} \;\overline{\diagdown}\; 30^\circ\, 00'\, 38'' \times 10.0924 \angle 114^\circ\, 59'\, 51'' = 95.3648 \times 10^{-3} \angle 84^\circ\, 59'\, 13''$ mho, or $10.48605 \;\overline{\diagdown}\; 84^\circ\, 59'\, 13''$ ohm, as shown at g and $\mathscr{R}$ in Fig. 7. The two arm impedances ρ_1 and ρ_2 are then found by subtracting $\mathscr{R}$ from R_{af} and R_{bf} respectively.

If we take the alternative form, as in Fig. 8, the staff admittance g' has the same size, but its slope differs from that of g Fig. 7, by 180°. In this case the basic T is realisable: while the alternative T is physically unrealisable, its staff impedance having a slope exceeding 90°, or a negative resistance component. Arithmetically, however, both T's are realisable. Both would yield the same terminal condi-

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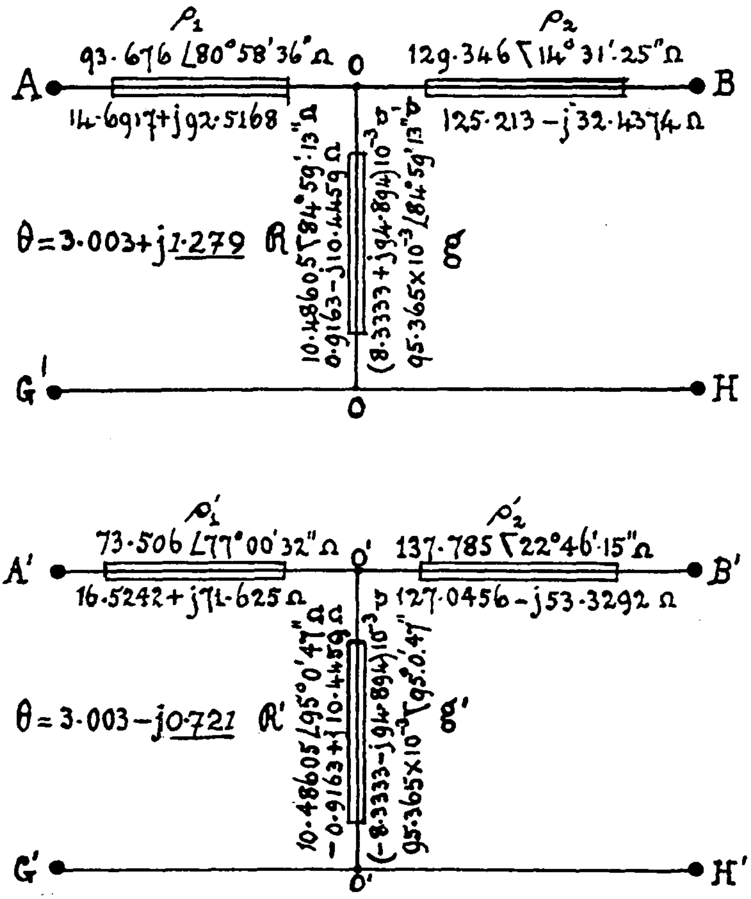
* Bibliography 3 and 4.


ρ₁
93·676 ∠80°58′36″ Ω
O
ρ₂
129·346 ⦬14°31′·25″ Ω
A
B
14·6917+j92·5168 Ω
125·213 −j32·4374 Ω
θ=3·003+j1·279
R
10·48605 ⦬84°59′·13″ Ω
0·9163−j10·4459 Ω
(8·3333+j94·894)10⁻³ ℧
95·365×10⁻³ ∠84°59′13″ ℧
g
G′
O
H
ρ′₁
73·506 ∠77°00′32″ Ω
O′
ρ′₂
137·785 ⦬22°46′·15″ Ω
A′
B′
16·5242+j71·625 Ω
127·0456−j53·3292 Ω
θ=3·003−j0·721
R′
10·48605 ∠95°0′47″ Ω
−0·9163+j10·4459 Ω
(−8·3333−j94·894)10⁻³ ℧
95·365×10⁻³ ⦬95°0·47″ ℧
g′
G′
O′
H′

FIGURES 7 and 8. Basic and Alternative Ts of Net in Fig. 6.

tions as to voltage, current and power, when connected up to output and input in the same manner as the actual net.

Proceeding to form the equivalent Π of the net, the architrave receives either of the duplicate impedances $z_{ab} \cdot \sinh \theta = 105.829 \angle 30° 00' 38'' \times \pm 10.0924 \angle 114° 59' 51''$, $= 1068.073 \angle 145° 00' 29''$ or 1068.073 ⦬ 34° 59′ 31″ ohms, as in Figs. 9 and 10. Here the basic Π happens to be physically unrealisable; while the alternative Π is realisable. The net of Fig. 6 might thus be replaced in any external or enveloping net, using the AG and BH terminals, by either the basic T or the alternative Π. The change from a basic to an alternative form of structure has the effect of reversing the direction, or sign, of the delivered voltage and current. The actual net of Fig. 6 would of course offer no ambiguity in this respect. When supplied with say 1 volt of alternating emf. and with standard phase at input terminals AG, it would deliver to an ammeter short circuiting the output terminals BH, a current definite both as to magnitude and phase; namely 0.936265 milliampere, leading the impressed voltage at AG by a phase of 34° 59′ 31″, as indicated over the architrave in Fig. 9B, and not with the opposite phase of −145° 00′ 29″, as indicated in Fig. 9A. Therefore the alternative Π would be justified; while the basic Π would be disqualified. In the absence of any tests to reveal the difference of phase between the input and output voltages or currents, there would be no means of distinguishing between the basic and equivalent structures. Either would yield the same apparent values of output voltage, current and power. The ambiguity as to the phase difference between input and output voltage or current is inherent in the system, until eradicated by some kind of comparative phase test. In the absence of such tests, either the basic or alternative T's and Π's may be used to represent the net, according to their realisability, or capability of being constructed in the laboratory.

In the case of an induction coil or air-cored transformer entering an alternating-current net, with primary input terminals and secondary output terminals, it is known that the same ambiguity of T's and Π's exists,* according to the relative direction of the windings in the coil with respect to the output terminals. In such a case, the ambiguity is not only inherent, as in other alternating-current cases; but is actually necessary, in order to explain the behavior of the apparatus in nets.

Three-Terminal Nets

If the second output terminal H is connected to the same point of the net as the second input terminal G, the four-terminal net becomes reduced to a three-terminal net as in Fig. 10, where output terminal H of Fig. 1 has been moved to coincide with input terminal G. In such a case, it is† known that for any continuous-current net there-

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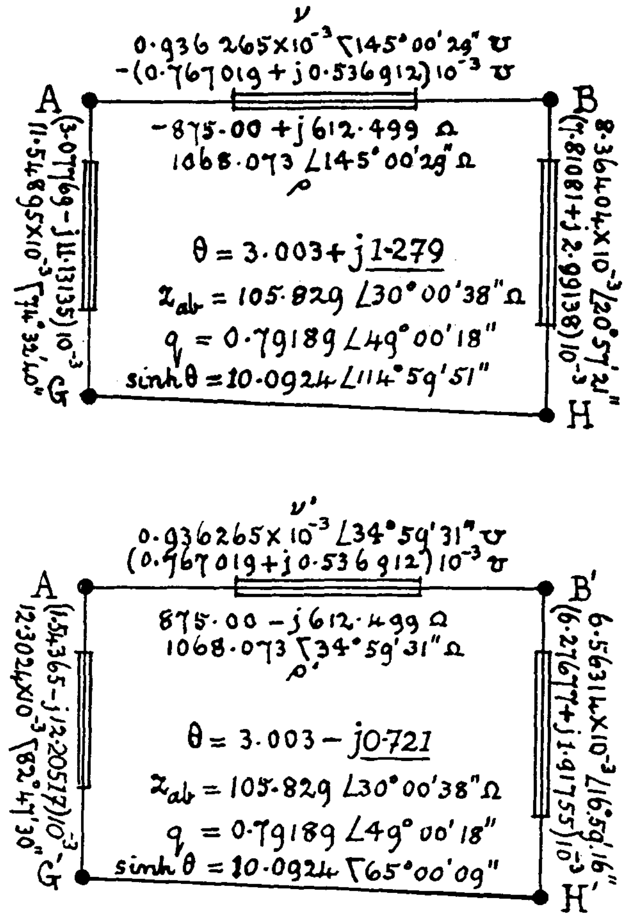
* Bibliography 6.

† Bibliography 7.


ν
0·936 265×10⁻³ ∖145°00'29" ℧
−(0·767019 + j0·536912)10⁻³ ℧
A
B
−875·00 + j612·499 Ω
1068·073 ∠145°00'29" Ω
ρ
θ = 3·003 + j1·279
z_ab = 105·829 ∠30°00'38" Ω
q = 0·79189 ∠49°00'18"
sinh θ = 10·0924 ∠114°59'51"
(3·07769 − j11·13135)10⁻³
11·548955×10⁻³ ∖74°32'46"
G
(7·81081 + j2·99138)10⁻³
8·364044×10⁻³ ∠20°57'21"
H
ν'
0·9362265×10⁻³ ∠34°59'31" ℧
(0·767019 + j0·536912)10⁻³ ℧
A
B'
875·00 − j612·499 Ω
1068·073 ∖34°59'31" Ω
ρ'
θ = 3·003 − j0·721
z_ab = 105·829 ∠30°00'38" Ω
q = 0·79189 ∠49°00'18"
sinh θ = 10·0924 ∖65°00'09"
(1·54365 − j12·20517)10⁻³
12·30242×10⁻³ ∖82°47'30"
G'
(6·27677 + j1·91755)10⁻³
6·563144×10⁻³ ∠16°59'16"
H'

FIGURES 9A and 9B. Basic and Alternative Πs of Net in Fig. 6.

fore devoid of reactance, the net resolves itself into a simple delta connection of three resistances *ABC*. In Fig. 11, the delta *ABC* results from the three-terminal net of Fig. 10. Keeping the testing leads *a*, *b* and *gh* fixed, and rotating the net clockwise into its three aspects, as shown in the Figure, the three geomean surge resistances are each and all equal to 3470.30 ohms, the three *q* inequality factors have unity as their product; while the three angles of the net, in its three successive aspects are such that the sum of their sinhs is 8.18249.

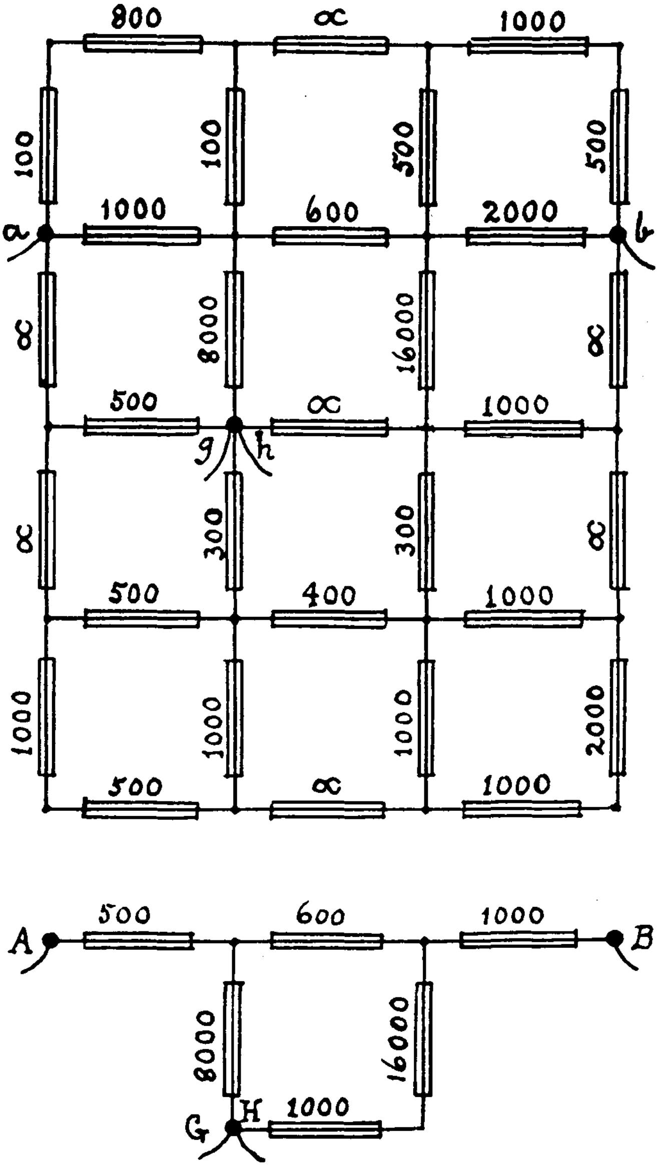

800
∞
1000
100
100
500
500
a
1000
600
2000
b
∞
8000
16000
∞
500
∞
1000
g
h
∞
300
300
∞
500
400
1000
1000
1000
1000
2000
500
∞
1000
A
500
600
1000
B
8000
16000
G
H
1000

FIGURE 10. Particular Rectangular D. C. Net and its Simplified Counterpart.

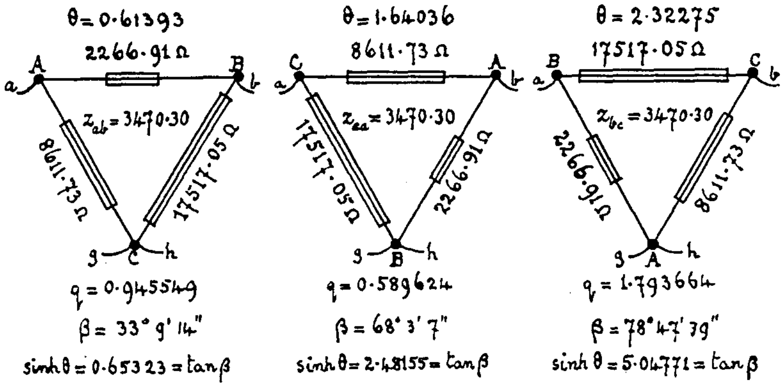

θ = 0·61393
2266·91 Ω
A
B
a
b
z_{ab} = 3470·30
8611·73 Ω
17517·05 Ω
g
C
h
q = 0·945549
β = 33° 9' 14"
sinh θ = 0·65323 = tan β
θ = 1·64036
8611·73 Ω
C
A
a
b
z_{ca} = 3470·30
17517·05 Ω
2266·91 Ω
g
B
h
q = 0·589624
β = 68° 3' 7"
sinh θ = 2·48155 = tan β
θ = 2·32275
17517·05 Ω
B
C
a
b
z_{bc} = 3470·30
2266·91 Ω
8611·73 Ω
g
A
h
q = 1·793664
β = 78° 47' 39"
sinh θ = 5·04771 = tan β

FIGURE 11. Three-terminal Net of Fig. 10 and its Three Aspects.

which is likewise their product. This means that the three corresponding gudermannian angles* of the net add up to 180°, or correspond to the three interior angles of a certain family of plane triangles. Although this gudermannian property has already been recognized in relation to continuous-current nets, it had to be relinquished for the general alternating-current net; because the three aspect angles θ of an alternating-current net being, in general, complex, would involve complex gudermannian circular angles β. Complex gudermannians have only recently been investigated;† so that having given any complex hyperbolic angle θ, its complex gudermannian circular angle β may be forthwith ascertained. It now appears that in the general case of an alternating-current three-terminal net, the three complex gudermannians are such that the three real components add up to 180°, or define a plane triangle; while the three imaginary components add up to zero, or mutually cancel in the additive process.

A. C. Three-Terminal Nets

A particular case of an alternating-current three-terminal net is represented in its three aspects by Fig. 12. The numerical details appear in Table III. It will be seen that there are six pairs of measured terminal impedances, or twelve values in all. These give rise to six different end surge impedances, from which the three geomean surge impedances are identical. The three inequality

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* Bibliography 7.

† Bibliography 8.

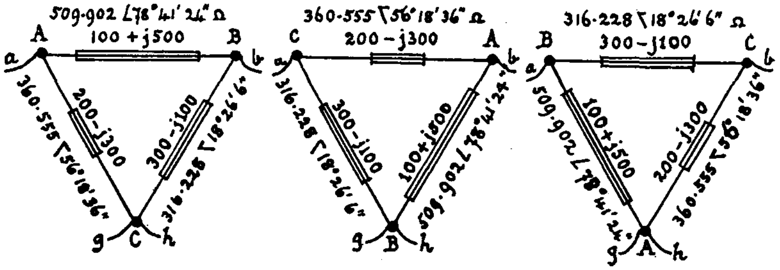
509·902 ∠78° 41′ 24″ Ω
A
100 + j500
B
a
b
360·555 ⦣56° 18′ 36″
200 − j300
300 − j100
316·228 ⦣18° 26′ 6″
g
C
h
360·555 ⦣56° 18′ 36″ Ω
C
200 − j300
A
a
b
316·228 ⦣18° 26′ 6″
300 − j100
100 + j500
509·902 ∠78° 41′ 24″
g
B
h
316·228 ⦣18° 26′ 6″ Ω
B
300 − j100
C
a
b
509·902 ∠78° 41′ 24″
100 + j500
200 − j300
360·555 ⦣56° 18′ 36″
g
A
h

Figure 12. Three-terminal Net in its Three Aspects.

TABLE III

DATA FOR THE THREE-TERMINAL ALTERNATING-CURRENT NET A B C OF FIG. 12

	Aspect BC	Aspect AB	Aspect CA
R_{ag} R_{af}	285.044 ∠ 15° 15′ 18″ 536.757 ∠ 30° 34′ 5″	509.902 ⦣ 11° 18′ 36″ 335.309 ⦣ 20° 46′ 20″	178.065 ⦣ 36° 5′ 6″ 187.444 ∠ 5° 47′ 34″
R_{bg} R_{bf}	178.065 ⦣ 36° 5′ 6″ 335.309 ⦣ 20° 46′ 20″	285.044 ∠ 15° 15′ 18″ 187.444 ∠ 5° 47′ 34″	509.902 ⦣ 11° 18′ 36″ 536.757 ∠ 30° 34′ 5″
z_{0a} z_{0b}	391.151 ∠ 22° 54′ 41″ 244.350 ⦣ 28° 25′ 43″	413.491 ⦣ 16° 2′ 28″ 231.149 ∠ 10° 31′ 26″	182.694 ⦣ 15° 8′ 46″ 523.157 ∠ 9° 37′ 44″
z_{ab}	309.157 ⦣ 2° 45′ 31″	309.157 ⦣ 2° 45′ 31″	309.157 ⦣ 2° 45′ 31″
q $1/q$	1.26521 ∠ 25° 40′ 12″ 0.790376 ⦣ 25° 40′ 12″	1.33748 ⦣ 13° 16′ 57″ 0.747674 ∠ 13° 16′ 57″	0.590945 ⦣ 12° 23′ 15″ 1.692207 ∠ 12° 23′ 15″
sinh θ	1.64933 ∠ 81° 26′ 55″ $0.245249 + j\,1.630996$	1.022872 ⦣ 15° 40′ 35″ $0.984824 - j\,0.276384$	1.166254 ⦣ 53° 33′ 5″ $0.692873 - j\,0.938122$
θ	$1.09336 + j\,1.38457$ $1.09336 + j\,\underline{0.881416}$ $1.09336 + j\,70° 19′ 39″$	$0.884274 - j\,0.196290$ $0.884274 - j\,\underline{0.124962}$ $0.884274 - j\,11° 14′ 48″$	$0.843072 - j\,0.749550$ $0.843072 - j\,\underline{0.477178}$ $0.843072 - j\,42° 56′ 46″$
$gd\,\theta = \beta$	$1.431919 + j\,0.680900$ $\underline{0.911588} + j\,0.680900$ $82° 2′ 35″ + j\,0.680900$	$0.797141 - j\,0.138505$ $\underline{0.507475} - j\,0.138505$ $45° 40′ 22″ - j\,0.138505$	$0.912532 - j\,0.542396$ $\underline{0.580937} - j\,0.542396$ $52° 17′ 3″ - j\,0.542396$

$$\Sigma \beta = \pi = 3.141592 = \underline{2.000000} = 180° 0' 0''$$

$$\Sigma \sinh \theta = \Pi \sinh \theta = 1.922946 + j\,0.416490$$

factors q have 1.0 ∠ 0° for their product, the sum of their slopes being 0°. The values of the three net angles θ, are given with their imaginary components in circular radians, circular quadrants and sexagesimal degrees. The underscored values are quadrantal. Similarly, the gudermannians β of the net are given with their real components in three forms. The sum of these three gudermannians is evidently π radians, $\underline{2.0}$ quadrants or 180 degrees. The plane triangle in Fig. 13 represents at ABC, the three real components of the gudermannians β, whose imaginary components add up to* zero.

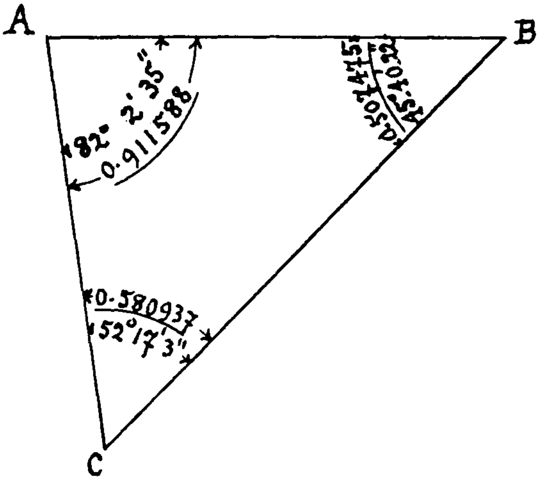

FIGURE 13. Plane Triangle Corresponding to the Three-terminal Alternating-current Net of Fig. 12.

The results of this particular three-terminal $a. c.$ net are of general application.

Summary of Results

1. Any net of more than three elements, having two input and two output terminals, and carrying steady currents of a single frequency (including zero frequency, or continuous currents as a limiting case)

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* The author is indebted for assistance in computing the case of Figs. 12 and 13, with Table III, to a group of five Chinese students, who undertook the task in subgroups, so organized as to furnish mutual checks upon the accuracy of the arithmetical work. Their names are Yun Chu, Pao G. Shen, Pinlu Shen, Shu Z. Shen and Tsen C. Tsao.

may be replaced by any one of four three-element artificial structures; viz, two *T*'s and two Π's, that may be separated into two classes,—basic and alternative.

2. In the continuous-current case, the basic *T* and Π are always physically realisable, and the alternative *T* and Π physically unrealisable.

3. The change from a basic to an alternative structure, or *vice versa*, reverses the direction or sign of the output voltage and current.

4. In any alternating-current net, any or all of the four arithmetically equivalent structures may be physically unrealisable. A physically realisable *a.c.* structure may be either basic or alternative.

5. The change from a basic to an alternative *a. c.* structure involves a change of 180° in the phases of output voltage and current, without affecting the phase difference between these two.

6. The ambiguity of phase between input and output voltage or current associated with basic and alternative structures, can be cleared up by some test which compares these phases. Such a test may disqualify either the basic or alternative structures.

7. Both basic and alternative structures may be needed for the adequate representation of nets containing air-cored induction coils.

8. The ambiguity of artificial structures pertaining to a net, is associated with the ambiguity of $j\pi$ radians, or $j\underline{2}$ quadrants, in assigning the value of a hyperbolic angle whose tangent is specified.

9. Three-terminal nets, whether carrying continuous or alternating currents, are hypothetically capable of being connected in three different aspects to input and output. The three corresponding net angles θ, have complex gudermannian angles β, whose imaginary components add up to zero, and whose real components add up to 180° or define a family of plane triangles.

10. In any symmetrical four-terminal net, the change from basic to alternative structure involves the substitution of z_0 coth $(\theta/2)$ for z_0 tanh $(\theta/2)$ in the T-arm impedances, and of y_0 coth $(\theta/2)$ for y_0 tanh $(\theta/2)$ in the Π-pillar admittances.

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LIST OF SYMBOLS EMPLOYED

β—Real gudermannian angle corresponding to real net hyp. angle (cir. radians).

$\beta = \beta_1 + j\beta_2$—Complex gudermannian angle corresponding to complex hyp. angle of an alternating-current net (radians $\angle$).

δ_a, δ_b—Position angles at input and output terminals of a net, under an assigned output load (hyps $\angle$).

E_a, E_b—Voltages at input and output terminals of a net (*rms.* volts $\angle$).

G_{ag}, G_{bg}—Admittances at input and output terminals, with opposite-end terminals shorted (mhos $\angle$).

g_1, g_2—Pillar admittances of an equivalent Π (mhos $\angle$).

$\theta = \theta_1 + j\theta_2$—Hyperbolic angle of a net (hyps $\angle$).

I_a, I_b—Input and output currents (amperes $\angle$).

$j = \sqrt{-1}$

ν—Architrave admittance of an equivalent Π (mhos $\angle$).

$\pi = 3.14159 \quad . \quad . \quad .$

q—Inequality coefficient of a net (numeric $\angle$).

R_{af}, R_{ag}—Impedances measured at input terminals when the output terminals are successively open and shorted (ohms $\angle$)

R_{bf}, R_{bg}—Impedances measured at output terminals when the input terminals are successively open and shorted (ohms $\angle$).

$\mathscr{R}$—Staff impedance of an equivalent T (ohms $\angle$).

ρ_1, ρ_2—Arm impedances of an equivalent T (ohms $\angle$).

ρ—Architrave impedance of an equivalent Π (ohms $\angle$).

Σ—Sign of summation.

σ—Impedance of a load connected to output terminals (ohms $\angle$).

z_{oa}, z_{ob}—Surge impedances of a net as found at input and output terminals respectively (ohms $\angle$).

z_{ab}—Geomean surge impedance of a net (ohms $\angle$).

$gd\ \theta$—Gudermannian angle of the hyperbolic angle θ (radians, degrees or grads).

Π—Sign of a product of multiplication, or sign of the equivalent *pi* of a net.

T—Sign of equivalent *tee* of a net.

a. c. contraction for *alternating current.*

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THE ELASTIC MODULI OF FIVE ALKALI HALIDES.

BY P. W. BRIDGMAN.

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Presented Oct. 9, 1929. Received Nov. 7, 1929.

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INTRODUCTION.

A knowledge of the elastic moduli of crystals is of much theoretical importance, but comparatively few have been determined. Perhaps the simplest of all crystals from the point of view of lattice structure are the alkali halides, but of these the elastic moduli only of NaCl have been determined at all satisfactorily, and of the others, determinations have been made on only two samples of KCl, of which one was obviously imperfect. The difficulty is in obtaining single crystals free from flaws in large enough pieces; the conditions are very much more exacting than in determining the cubic compressibility, for example.

By a development of the method which I have used for the production of single crystals of the metals,[1] it has been possible to produce single crystals of five alkali halides, namely NaCl, NaBr, KCl, KBr, and KI, large enough to permit cutting from them rods on which measurements of the elastic moduli could be made.

METHODS.

Method of Making the Crystals. The method is that of slow cooling from the melt, the material to be crystallized being placed in a suitable mold, and slowly moved from the interior of a furnace maintained above the melting temperature to an external colder region. The greatest difficulty in extending this method from metals, for which it works easily, to salts, is the great propensity of salts to crack into small pieces on cooling to room temperature. This is an effect of temperature contraction combined with the great brittleness of the salts. Temperature contraction may result in cracking either when the salt sticks to the walls of the mold, or when there is too steep a temperature gradient while withdrawing from the furnace. The difficulty with steepness of gradient can to a large extent be avoided by suitable design, but it is not possible to reduce the gradient indefinitely without danger that the isothermal surface at the solidifying temperature have more than one sheet, when crystallization may start from more than one nucleus. The difficulty from sticking to the walls of the mold was in large part avoided by making the mold of platinum foil 0.001 inch thick, as was first done by Ramsperger and Melvin.[2]

In order to determine the elastic constants it was necessary to get the specimen into the form of a slender rod. In order to avoid casting large blocks in single crystal form from which the rods could be cut, the casting was made at once in the form of a rod. The natural method would be to make the mold in the form of a thin tube, like the glass capillaries in which the metals were cast, but this did not prove successful. There were difficulties in making the mold out of the thin foil, but the greatest difficulty was in getting the casting out of the mold without cracking it. Finally the molds were made in the form of open boats, used in a horizontal position. This demanded, of course, that the axis of the furnace be placed horizontally rather than vertically. The boats were bent from pieces of foil 8.3 cm long and 1.9 cm wide; the ends were welded together, and the edges bent double to increase the transverse stiffness. At first the joints in the boats were made with pure gold solder, but this was given up because gold is soluble in the molten salts, and it was very difficult to use such a small quantity of gold as not to appreciably discolor them. One very important point in making the boats is that the platinum must be slightly crinkled, instead of being left perfectly smooth; the crinkling provides enough elastic yield to prevent the cracking which otherwise takes place. The cold casting could be removed from the boat without great difficulty by working the platinum foil away from the casting with the thumbs of the two hands simultaneously, as will readily suggest itself on trial. It was never possible to use the foil more than once. No substitute was found for platinum, although several were tried. The most nearly successful was silver, but this slowly dissolves in the molten salt.

In the furnace the boats with their contents were protected from drafts and any furnace fumes by enclosing them in quartz test tubes, with stoppers ground so as not to be quite a perfect fit, thus allowing thermal expansion of the air within. Several of the quartz test tubes with their contents were made together into a bundle with a suitable holder, and withdrawn simultaneously from the furnace, so that several castings could be made at the same time.

The furnace was made in two parts with independent windings. In one half the temperature was maintained by a suitable current 10° or 20° above the melting temperature, and in the second part at a temperature somewhat below the melting temperature; the proper relation between the two temperatures had to be determined by trial. The temperatures of the two parts of the furnace were read on thermocouples, so connected with potentiometer circuits as to give a sensitivity of considerably better than a degree. Temperature was maintained constant within a degree or so by manual regulation during the process of withdrawal. Current was supplied by an independent generator of much constancy, so that the manual regulation was not difficult. The molds were drawn from the hot part to the colder part at a rate of the order of 10 cm per hour. When the mold was entirely in the colder part, the current was gradually cut down, and finally the furnace allowed to cool over night. Too rapid cooling after solidification was responsible for the loss of a number of crystals.

After the castings are removed from the mold, they must be checked to make sure that they are one grain. A simple way of doing this is to rub the surface of the casting lightly with a moist cloth, etching it slightly. When the moisture has dried off, it is very easy to tell by the appearance of the reflection pattern whether there is more than one grain. If the crystal passed this test, it was then formed into a slender cylinder. This was done in a jeweller's lathe, and of course required some care, but after some practice it was not difficult to get rods sometimes 5 cm long and 0.28 cm in diameter, round and true over the entire length to 0.0002 cm.

After the measurement of the elastic constants, to be described later, the orientation of the crystal axes was determined by making the principal cleavage planes with a knife blade, and measuring the angles with a protractor. The angles of all three planes were measured; the consistency of these three measurements thus furnished an internal check on the correctness of the orientation. The measured angles were adjusted so as to make the sum of the squares of the three direction cosines equal to unity, dividing the necessary adjustment among the angles proportionally roughly to the squares of the sines of the angles. The adjustment was practically never larger than a degree or two. The cleavage planes were determined at both ends of the rods, thus giving an additional check that the rods were truly one grain, and on the orientations.

The nature of the material will be described in detail in the presentation of data for the individual substances. One general remark is to be made, namely that slight and obscure impurities play a much more important part than I appreciated at first. In several cases a long series of unsuccessful results with salt from one source was followed by immediate success when the material was replaced by salt from another source, of no greater presumptive purity. In some cases the original material contained enough water so that there was violent snapping and jumping about of the salt on heating to the melting temperature. These materials were dried by a preliminary fusion, either in quartz or in a platinum crucible. An especially effective method of preliminary treatment is to cast the salt by the regular procedure for making single crystals, melting it in a large quartz test tube and slowly lowering in a vertical position through the furnace. The lower part of the resulting block was usually as clear as glass, except for the numerous cracks, and this clear material was used in making the final castings in the platinum boat.

Measurements of the Moduli. A cubic crystal has three independent elastic moduli, so that at least three different measurements must be made. There is a great deal of latitude as to what these may be; if perfect accuracy were attainable, either three independent different sorts of elastic deformation might be measured on a single specimen, or measurements of the same sort of deformation, as a bending, for example, might be made on three different samples of different orientations. The experimental accuracy is far from perfect. however, so that many observations, of different kinds of deformation on different samples, were desirable. The sort of deformation that is easiest to measure is the bending and twisting of rods, and the measurements made in connection with this paper were of the bending and twisting of rods of a variety of orientations. In addition, the linear compressibility may be measured. This has already been determined by Slater[3] for all the salts of this paper; it can be measured with high accuracy, is not much affected by imperfections in the specimen, and there are values by other observers against which the values of Slater may be checked. In calculating the elastic moduli from the data of this paper, I have assumed that Slater's values for the compressibility are correct.

The experimental determinations of bending and twisting were made by methods conventional enough not to need extended description. In determining the bending, the round rod was supported at each end on V-shaped knife edges, the distance between the end supports being about 2.5 cm. The load was applied to a scale pan slung from the center with a double loop of cotton thread. Pressed up by a spring against the under side of the rod at the center between the loops of thread was a link arrangement, by which any vertical displacement of the center was transmitted to a conventional rocking mirror. The two ends of the rod were pressed against the V-shaped notches by springs with greater force than the upward force on the link. The scale distance was about 4.5 m, and the width of the mirror rocker 0.11 cm, so that the magnification was about 8000. The load was applied to and removed from the pan with a spring arrangement to avoid shock. In most cases the load was 20 gm, but for two of the less deformable salts was 40 gm. The displacements of the scale observed in the telescope for this load were of the order of 1.5 cm, and this could easily be read to 0.1 mm. At first, readings were made at both half and full load. The reading with half load came out so consistently equal to half the reading with full load that continued check of this point seemed superfluous, and the later readings were made only with full load. The readings were made immediately after the application and removal of load, so that strictly these are measurements of the adiabatic moduli; the difference between adiabatic and isothermal modulus is disregarded in the following. The effective bending modulus of a round rod cut from a cubic crystal should be the same for all orientations of the rod about the axis; this was always checked by making readings on each rod for four orientations spaced 90° apart. At each orientation, five readings of the displacement under full load were made. The readings in different orientations did not always agree, but differed by only a few per cent, and in no consistent manner; the average of all the readings was taken in calculating the effective bending modulus.

The twist was determined with apparatus that had already been used in determining the twist of slender single crystal rods of the metals. The specimen is held rigidly at one end, and at the other end is attached to the arm through which the twisting couple is applied through an arrangement of knife edges so that the couple acts practically without friction. The maximum twisting moment applied to these rods was about 170 gm cm. The twist is observed in telescope and scale in two mirrors, attached by a spring arrangement of obvious enough design to the central part of the rod. The mirrors must be far enough from the ends of the rods to avoid end effects; the usual distance between the mirrors was of the order of 2 cm, and the clear length of the rod about 4 cm. The twist was determined from the difference of reading of the two mirrors. The proportionality between twist and moment was tested in every case, and no deviation found within experimental error, which might be perhaps as much as 1%. The scale was 4.5 m distant, and the difference of the two deflections of the order of 1 cm, and the optical system was good enough to permit the certain estimation of 0.1 mm. Ten or a dozen readings of the twist of each rod were usually made, and the average taken.

The rods were attached to the two end pieces with cement. At first, elaborate precautions were taken not to heat the rods in applying the cement more than a few degrees, and paraffine and other low melting substances were used as cement. These were all unsatisfactory, and many times the specimen slipped. Finally it was found that these slender rods can stand much apparent abuse, and they were cemented into the holders with deKhotinski cement, melted into position with a small gas flame, which many times fell directly on the specimen without cracking it. It is surprising how difficult it is to crack one of these rods by unequal heating. I hoped to be able to get the cleavage planes by a local heating, instead of fracturing with a knife blade, but without success. Cooling in liquid air was also ineffective in producing the desired fracture. There must, however, judging by the behavior of the specimens as they come from the furnace, be a region near the melting point where the salt is very brittle and very sensitive to temperature inequalities.

The fundamental elastic moduli are connected with the bending and twisting moduli by formulas which may be found in Voigt.[4] For the bending of a round bar, we have the formulas:

$$u = \frac{WL^3 s_{33}'}{12\,\pi\, a^4}, \tag{1}$$

$$s_{33}' = s_{11} - 2\,\{s_{11} - s_{12} - \tfrac{1}{2} s_{44}\}\,\{\gamma_2^2\gamma_3^2 + \gamma_3^2\gamma_1^2 + \gamma_1^2\gamma_2^2\}. \tag{2}$$

Here u is the displacement under the weight W of the center of the rod, the length of which is L and the radius a. γ_1, γ_2, and γ_3 are the direction cosines of the three crystal axes referred to the length of the rod. s_{11}, s_{12}, and s_{44} are the three elastic moduli to be determined, referred in the conventional way to the principal crystal axes. That is, stress and strain are connected by the relations:

$$\left.\begin{aligned} e_{xx} &= s_{11} X_x + s_{12} Y_y + s_{12} Z_z \\ e_{yy} &= s_{12} X_x + s_{11} Y_y + s_{12} Z_z \\ e_{zz} &= s_{12} X_x + s_{12} Y_y + s_{11} Z_z \end{aligned}\right\} \qquad \left.\begin{aligned} e_{yz} &= s_{44} Y_z \\ e_{zx} &= s_{44} Z_x \\ e_{xy} &= s_{44} X_y \end{aligned}\right\}.$$

For the twist we have:

$$n = \frac{N}{\pi a^4}(s_{44}' + s_{55}'), \tag{3}$$

$$(s_{44}' + s_{55}') = 4\,(s_{11} - s_{12}) - 4\,\{s_{11} - s_{12} - \tfrac{1}{2} s_{44}\}\,\{\gamma_1^4 + \gamma_2^4 + \gamma_3^4\}. \tag{4}$$

Here n is the twist per unit length, and N is the twisting moment.

Also, the cubic compressibility χ is given by:

$$\chi = 3\,(s_{11} + 2\,s_{12}). \tag{5}$$

We now have the problem of determining the best values for the three moduli s_{11}, s_{12}, and s_{44} from measurements on a large number of specimens. Equation (1) may be solved for s_{33}' in terms of the dimensions and the measured displacement u, and (3) may be solved for $s_{44}' + s_{55}'$ in terms of twist and dimensions, and these values substituted in (2) and (4). The result of this is two linear equations in the three unknown moduli, the coefficients being known functions of the orientations. Next, taking the compressibility as known from equation (5) express s_{12} in terms of the known compressibility and s_{11}. Substituting this value for s_{12} back into (2) and (3) gives two linear equations in the two moduli s_{11} and s_{44}, the coefficients being function of the orientations, displacements, and compressibility. Finally, by dividing these equations through by the constant term, they may be written in the form:

$a_{11}\, s_{11} + a_{12}\, s_{44} = 1$, (6), from bending measurements.

$a_{21}\, s_{11} + a_{22}\, s_{44} = 1$, (7), from twisting measurements.

For any particular rod, after the measurements have been completed, the values of a_{11} and a_{12} are known from the measurement of bending, or a_{21} and a_{22} from the measurements of the twist. But whatever the values of a_{11} etc., they must be consistent with a single definite pair of values of s_{11} and s_{44} when substituted into (6) or (7). But now if we regard a_{11} etc. as variables, then (6) or (7) is the equation of straight line with intercepts $1/s_{11}$ and $1/s_{44}$, the intercepts, and hence the line represented, being the same for either (6) or (7). Writing (6) or (7) in the common form

$$a_1 s_{11} + a_2 s_{44} = 1, \tag{8}$$

the following procedure is at once suggested. From the measurements of elastic distortion, dimensions, and orientation, obtain for each specimen an equation in the form (8). Plot the coefficients a_1 and a_2 as points in an $a_1 - a_2$ plane. There will be as many of these points as there are independent measurements of elastic distortion. These points must all lie on the same straight line, the intercepts of which on the axes are $1/s_{11}$ and $1/s_{44}$. The best values for the moduli from a number of independent measurements I assume to be given by the intercepts of the best line that can be drawn through all the points, and the internal consistency of the measurements on different samples is shown by the accuracy with which the points lie on a single line.

It is obvious that the greatest accuracy would be obtained by so locating the points as to lie as near the axes as possible. An inspection of the equations shows at once what this involves. If one of the principal axes lies along the length of the rod, only s_{11} occurs in (2), and only s_{44} in (4), so that bending and twisting measurements on rods of these orientations would give directly s_{11} and s_{44}. Unfortunately, this orientation is one that does not often spontaneously occur, but the rods naturally grow from the melt in intermediate directions, as will be apparent from the detailed presentation of the data. Only in the case in which I repeated Voigt's measurements on NaCl cut from large natural blocks was the most favorable orientation exactly attained.

DETAILED DATA.

KI. This was the first substance attempted, and much more time was spent on it than on any of the others. A considerable part of the time was spent in finding the various best details of the method. All the early work was done with material from Kahlbaum, of the highest purity which they manufacture, but not their "K" grade. I anticipated that KI would be the easiest of all the materials to crystallize, because Slater had found it so, but although a great many attempts were made, only five specimens in all were obtained on which it was possible to measure the elastic distortion. Even these specimens were not all satisfactory, as it was not always certain that the specimens were truly one grain, and the results were very scattering. After no further improvement in the technique seemed easily possible, this material was given up, somewhat in despair, and KBr tried, which was obtainable in Kahlbaum's "K" grade. The first attempt was brilliantly successful. The obvious explanation of the difference was in the difference of purity of the two materials, and it therefore became important to obtain KI of greater purity. Finally I was fortunate to obtain some of the old stock of Powers, Weightman, and Rosengarten, now no longer manufactured. This proved adequate, giving clear castings with sharp cleavage planes from which the rods were readily machined in the lathe. To a cutting tool the consistency of KI is much like that of horn or celluloid; in progressing through the series of halides toward smaller atomic weights the hardness and accordingly the difficulty in turning increases.

Five specimens were made with the pure material, which gave good single crystals and satisfactory determinations of the elastic moduli. The results obtained with these five specimens, and also with the best of the Kahlbaum material, are shown in Figure 1, the coefficients of s_{11} and s_{44} being plotted in the way already described. The points all lie on a straight line within the limits of error. In determining these coefficients Slater's value used for the compressibility was 8.54×10^{-12} Abs. C. G. S. It is unfortunate that the orientations were not more favorably distributed. It will be seen that only one of the specimens approximately satisfied the condition of most favorable orientation with one cleavage plane perpendicular to the length. The method used for producing the crystals gives no direct control of the orientation, although it might be modified to do so, and one has to trust more or less to luck to get what is needed. A number of other perfect single grain specimens were made in addition to those measured, in an endeavor to get some with more favorable orientations, but without success.

An attempt was made to determine the effective Young's modulus, that is, the modulus s_{33}', directly by measuring the extension when stretched by a weight, but the shortness of the specimen made it difficult to eliminate various irregularities arising from the end effects, and the attempt was abandoned in favor of the more convenient method by bending.

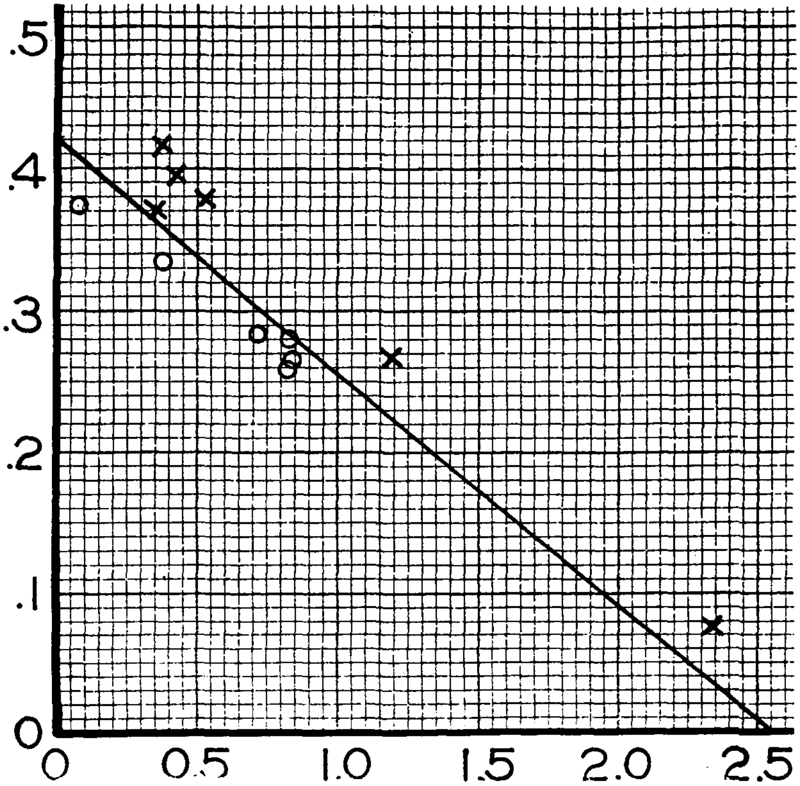

Figure 1. The coefficients of $s_{11} \times 10^{-11}$ in equation 8 plotted as abscissas against the coefficients of $s_{44} \times 10^{-11}$, for potassium iodide. The points obtained from bending measurements are shown as crosses, and those from twisting measurements as circles. If there were no experimental error the points should all lie on a straight line.

KBr. The material used was Kahlbaum's, grade "K," as has already been explained. Measurements were made on eight specimens, of which only three were measured for torsion. It is more difficult to get a good specimen for the torsion measurements than for bending, because the length must be greater.

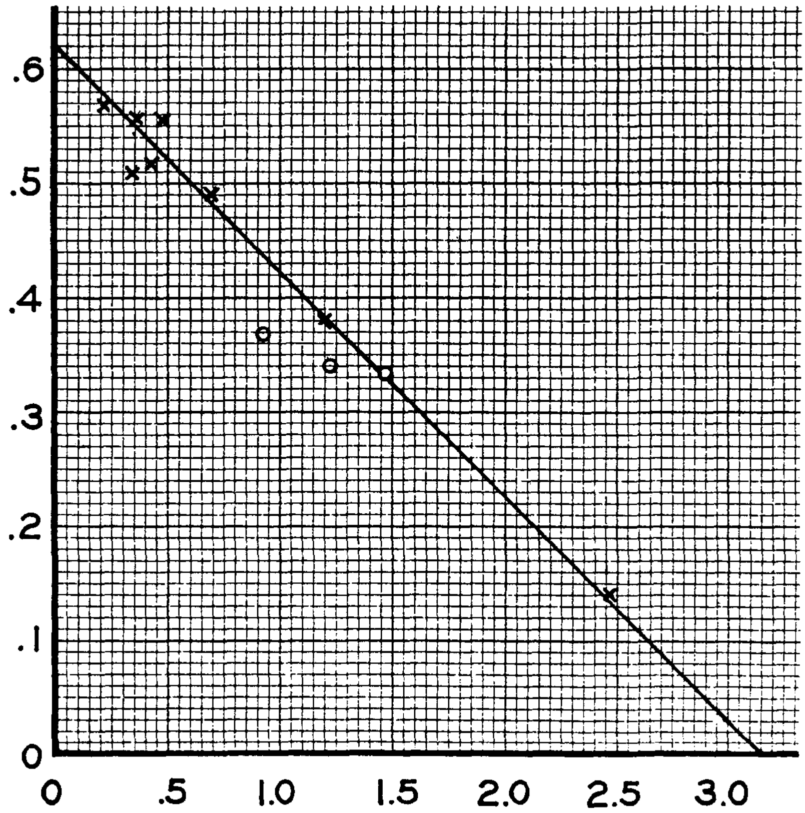

Figure 2. The coefficients of $s_{11} \times 10^{-11}$ in equation 8 plotted as abscissas against the coefficients of $s_{44} \times 10^{-11}$, for potassium bromide. The points obtained from bending measurements are shown as crosses, and those from twisting measurements as circles.

The coefficients of s_{11} and s_{44} are plotted in Figure 2, and again it will be seen that the points lie on a straight line, as is demanded by the crystal symmetry. Slater's value for the compressibility of KBr is 6.69×10^{-12}.

KCl. This was from Kahlbaum, grade "K." In spite of the high melting point, this was distinctly the easiest to work with of the materials tried. The rods were beautifully clear, always one grain, long enough for the torsion measurements, and of considerable

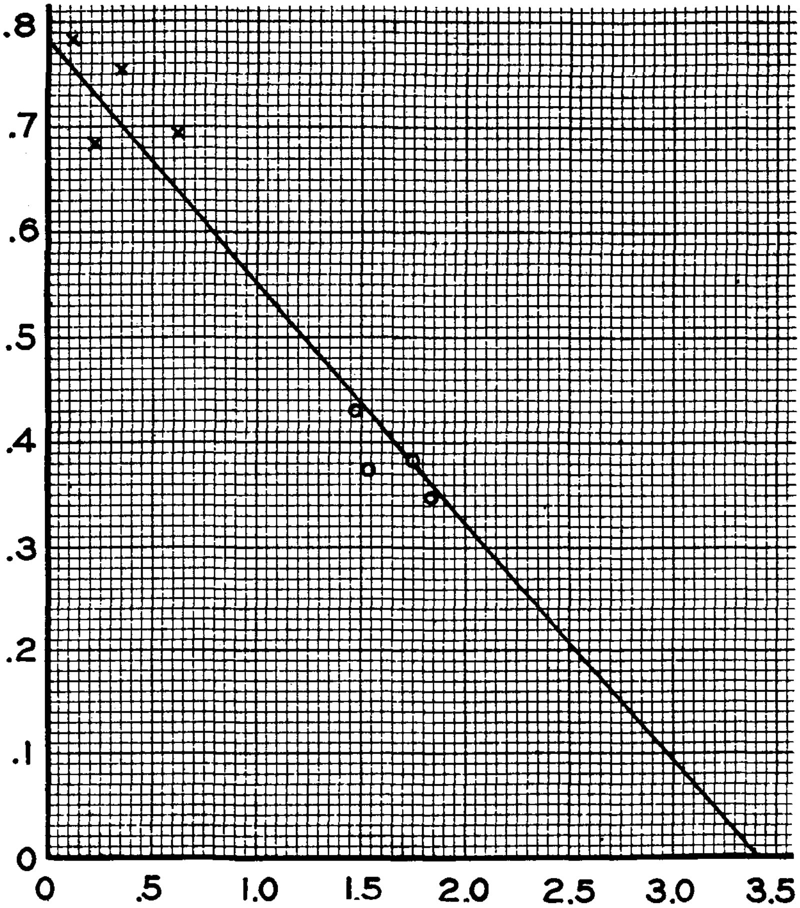

Figure 3. The coefficients of $s_{11} \times 10^{-11}$ in equation 8 plotted as abscissas against the coefficients of $s_{44} \times 10^{-11}$, for potassium chloride. The points obtained from bending measurements are shown as crosses, and those from twisting measurements as circles.

mechanical strength, so that turning was an easy process. Bending and torsion measurements were made on four specimens; the coefficients of s_{11} and s_{44} are plotted in Figure 3. The points lie on a straight line within the limits of error. Slater's compressibility is 5.64×10^{-12}.

NaBr. Attempts to prepare single crystals of this from the purest material that I could purchase were not successful. Professor Baxter was, however, so kind as to have prepared from his stock of atomic weight material some of this salt of unusual purity. Enough of the pure material was available for three crystals; all of this was cast successfully as single grains. Unfortunately the one of these which would have given the most accurate information, with a cleavage plane nearly perpendicular to the length, broke in turning. This, of course, is much more likely to happen when the cleavage plane is perpendicular, an exasperating situation. Satisfactory measurements were made of the bending and twist of the two remaining specimens, and the results are shown in Figure 4, plotted in the regular way. The 40 gm. weight, instead of that of 20 gm., was used in making the bending measurements. Slater's compressibility for this is 5.08×10^{-12}.

NaCl. These measurements were made mostly by way of check, there being no a priori reason to think that the material on which Voigt worked was not satisfactory. The material used was natural rock salt, which can be obtained in large clear blocks. In addition to the natural material one single grain specimen was prepared by crystallization from the melt from salt of Powers, Weightman and Rosengarten. The bending and twisting of this specimen was measured, and also its compressibility, as will be described later.

The natural crystal blocks were of German origin, obtained through Ward's Natural History Establishment. Three rods were cut from one block, and two from another. They were cut perpendicular to the cleavage planes, so that bending and twisting measurements gave directly s_{11} and s_{44}. Three rods from the first block gave for s_{11} .216, .209, and $.212 \times 10^{-11}$ respectively, and the two from the second: .230 and $.232 \times 10^{-11}$. It would thus appear that there are differences between the elastic moduli of rods cut from different blocks greater than the experimental error. This result emphasizes a conclusion that has been becoming increasingly evident lately, namely that it is very seldom that natural crystals are the unique things that have been supposed. Twisting measurements were made on only one rod from each block; these gave for s_{44} .782 and

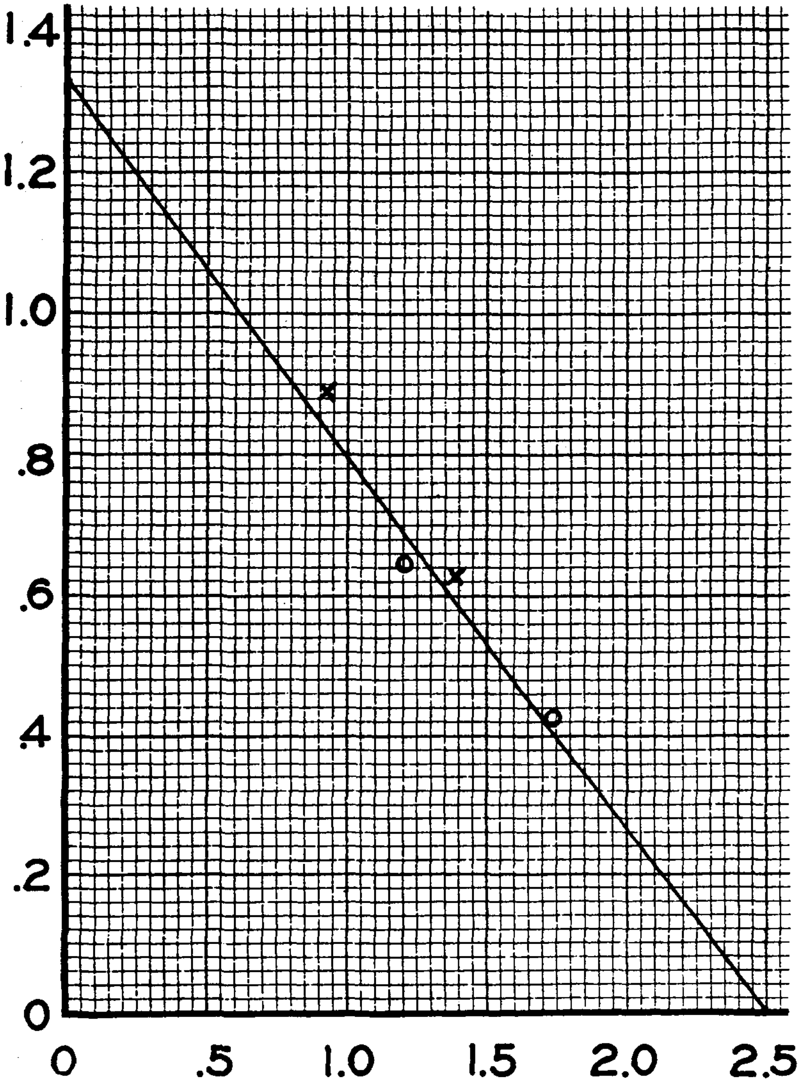

Figure 4. The coefficients of $s_{11} \times 10^{-11}$ in equation 8 plotted as abscissas against the coefficients of $s_{44} \times 10^{-11}$, for sodium bromide. The points obtained from bending measurements are shown as crosses, and those from twisting measurements as circles.

$.742 \times 10^{-11}$ respectively. The values which Voigt gives for natural NaCl are: $s_{11} = .243 \times 10^{-11}$, $s_{12} = -.0527 \times 10^{-11}$, $s_{44} = .788 \times 10^{-11}$. In the following I have selected as the most probable values: $s_{11} = .23 \times 10^{-11}$ $s_{12} = -.05 \times 10^{-11}$, $s_{44} = .78 \times 10^{-11}$. The values of bending and twist of the sample crystallized from the melt were not inconsistent with these values. The orientation was not favorable, however, so that no weight can be attached to the values of the moduli which would be given by a rigorous calculation from the two measurements.

The compressibility of the sample crystallized from the melt was measured in the regular way to a maximum pressure of 12000 kg/cm^2 at 30° and 75° C, and the following results found:

$$\left.\begin{array}{l}\text{At } 30^\circ,\ -\Delta V/V_0 = 41.82 \times 10^{-7}\, p - 50.4 \times 10^{-12}\, p^2 \\ \text{At } 75^\circ,\ -\Delta V/V_0 = 43.44 \times 10^{-7}\, p - 51.9 \times 10^{-12}\, p^2\end{array}\right\}.$$

Here pressure is expressed in kg/cm^2 units, as in all my compressibility measurements. The average deviations of single readings from a smooth curve at these two temperatures were 0.13 and 0.21 % respectively, which is about the average accuracy for material of this nature.

There is some interest in this compressibility measurement since nearly all previous measurements of the compressibility of NaCl, of which there have been a number, have been made on the natural crystal. One would expect the artificial material, which starts with a chemical of known high purity, to be more pure than the natural material, and hence the compressibility measured with it to be more significant.

The compressibility values just given yield, when converted into Abs. C. G. S. units:

$$\left.\begin{array}{l}\text{At } 30^\circ,\ -\Delta V/V_0 = 4.263 \times 10^{-12}\, P - 5.23 \times 10^{-23}\, P^2 \\ \text{At } 75^\circ,\ -\Delta V/V_0 = 4.428 \times 10^{-12}\, P - 5.38 \times 10^{-23}\, P^2\end{array}\right\}.$$

Slater's value for the natural crystal at 30° was $4.20 \times 10^{-12}\, P - 4.60 \times 10^{-23}\, P^2$, and at 75° $4.33 \times 10^{-12}\, P - 4.74 \times 10^{-23}\, P^2$. The second degree formulas just given were calculated by me from Slater's results, which were tabulated in somewhat different form. The difference between the results of Slater and me is not large, but the sign of the difference is unexpected, the natural crystal being initially less compressible. The difference between the two results is not as great as would appear at first, there being a compensation between the first and second degree terms; the total volume change at the maximum pressure of 12000 kg/cm^2 given by Slater's formula is not quite ½ % *greater* than given by mine.

The initial compressibility at 20° of the artificial crystal is 4.23×10^{-12} by extrapolation from my formula above, and 4.17×10^{-12} by extrapolation from Slater's for the natural crystal. The value of Adams, Johnston, and Williamson[5] for the natural crystal at the same temperature was 4.12×10^{-12}, and that of Madelung and Fuchs[6] 4.14×10^{-12}. Richards[7] is the only observer who has previously measured the compressibility of both the natural and the artificial crystal, and he finds the natural crystal somewhat *more* compressible, but since he gives only two significant figures for the natural crystal and three for the artificial, it is probable that too great significance should not be attached to this difference. His value for the artificial material was 4.30×10^{-12} and 4.5 and 4.6×10^{-12} for two samples of the natural crystal. Both his values are distinctly larger than those of other observers.

The maximum variation in compressibility between any of the observed values is not great enough to introduce appreciable changes in the values given for the moduli as calculated from observations on bending, twist, and compressibility.

Other Salts. Unsuccessful attempts were made to crystallize some of the other alkali halides, but no great effort was expended on these, and others should not be deterred by my failure. The lithium salts are difficult to manage either because they are very hygroscopic, or because they cannot be obtained in sufficient purity. NaI could not be obtained in sufficient purity. Professor Baxter was so kind as to partially purify my commercial material by recrystallization from aqueous solution. This treatment would be expected to remove any organic impurities, but this did not prove to be sufficient. RbCl was also attempted; I had a very small supply left from the material prepared by Professor Richards, the polymorphic transitions of which under pressure I had measured. Dr. Paul Anderson was so kind as to remove by electrolysis the iron which had got into it during the pressure manipulations, but this did not prove to be sufficient.

SUMMARY AND DISCUSSION.

In the following table are given the values of the elastic moduli obtained from the compressibilities and the intercepts on the axes of the lines already shown in the figures for the various salts. The number of significant figures given for NaCl is less than for the others because of the uncertainty arising from the variation in the different samples of the natural crystal.

TABLE.

ELASTIC MODULI IN ABS. C. G. S. UNITS.

Salt	s_{11}	s_{12}	s_{44}
NaCl	$.23 \times 10^{-11}$	$-.05 \times 10^{-11}$	$.78 \times 10^{-11}$
NaBr	.400	$-.115$	.754
KCl	.294	$-.053$	1.27
KBr	.317	$-.047$	1.61
KI.	.392	$-.054$	2.38

The most important question in connection with these elastic moduli, and which was decisive in my decision to attempt their measurement, is whether Cauchy's relation holds. Expressed in terms of the elastic constants this is $c_{12} = c_{44}$; in terms of the moduli it is more complicated, being

$$(s_{11} - s_{12})(s_{11} + 2 s_{12}) = - s_{12} s_{44}.$$

In the case of the general crystal the relations of Cauchy are more complicated, and reduce the 21 constants required by general considerations of thermodynamics and crystal symmetry to 15. These relations were deduced by Cauchy on the assumption that the forces between the elements of the crystal structure have spherical symmetry. It is known that in general the relations cannot be correct, as shown by the experimental measurement of the elastic constants of a large number of different crystals by Voigt. An adequate theoretical account is given of the situation by Born's theory of crystal lattices;[8] the failure of the Cauchy relation is shown to be connected with the possibility of a rigid relative displacement with respect to each other of the elementary lattices of which the crystal is composed. The fact that Cauchy's relation does not apply to cubic crystals of the metals must be taken, according to Born's theory, to mean that the displacements of the atomic nuclei relative to the surrounding cloud of electrons play an essential part in the elastic phenomena of metals. The situation is simpler with regard to the alkali halides than with regard to the metals. If the alkali halide structure can be adequately represented by interpenetrating cubic lattices of positive and negative ions, the attractive forces being the electrostatic forces and the repulsive forces some high inverse power of the distance, then Born's theory reduces to Cauchy's, so that the Cauchy relation should hold. Now there is considerable physical evidence, apart from the elastic behavior, to suggest that this is an adequate picture of the interatomic forces, and consequently the expectation is that the Cauchy relation will hold. The expectation that the relation will hold is much strengthened by the new wave mechanics,[9] because according to this a complete electron shell must have perfect spherical symmetry, and not the sort of cubic symmetry that Born at first supposed, and furthermore the ions of the lattice are composed of complete shells.

The experimental check of the Cauchy relation has, however, been meagre. The only satisfactory material hitherto available has been NaCl, for which the measurements of Voigt[10] showed the relation satisfied. Voigt[10] also measured KCl, but his material was not satisfactory in that only two specimens were available, not perfectly free from flaws. The values of the elastic constants obtained from the two specimens of KCl were quite different. Voigt was inclined to take the average of the constants from the two specimens as giving the most probable value, in which case the Cauchy relation was far from satisfied. Försterling[11] remarked, however, that one of Voigt's specimens was evidently much poorer than the other, because the cubic compressibility calculated from its elastic constants failed by a large amount to agree with the direct experimental value of other observers, whereas the other specimen gave agreement. Discarding the poorer sample, the other sample of KCl approximately satisfied Cauchy's relation. In general, therefore, the experimental check could not be called satisfactory. It was still less satisfactory when it is considered that NaCl and KCl might give a fortuitous check because of their position somewhere near the middle of the alkali halides series, whereas the more extreme members of the series might not give a check. A very similar situation arose with respect to the inverse ninth power of repulsive force demanded by Born's original theory of compressibility; the ninth power was found for NaCl, but not for the extreme members of the alkali halide series.

The following procedure was adopted in examining experimentally whether the Cauchy relation holds for the salts measured above. It will be remembered that, assuming the experimental determination of compressibility to have higher accuracy than the other elastic moduli, the results of the bending and twisting measurements on rods of different orientations could be plotted in such a way that all points must lie on a single straight line. The intercepts of this line determined the moduli s_{11} and s_{44}. In general, there is no necessary connection between s_{11} and s_{44}, so that a two-parameter family of lines is available to represent the results. But if the Cauchy relation holds, there is an additional relation between the moduli, so that if s_{11} is given, s_{44} is determined, and the possible straight lines by which the experimental results can be represented become a one-parameter family. In detail, $s_{12} = \frac{1}{2}(k - s_{11})$ where k is the linear compressibility, and substituted into the Cauchy relation this gives

$$s_{44} = \frac{k(3s_{11} - k)}{s_{11} - k}.$$

This determines the s_{44} intercept when the s_{11} intercept and the compressibility are fixed.

The lines given in all figures have been drawn subject to this restriction. Although in each of the figures it is probable that exactly the line shown would not have been drawn if a least squares determination had been made of the best line for each figure taken by itself, nevertheless in each case the line shown comes very close to the line that would have been drawn with no ulterior consideration. Hence the conclusion may be drawn that the Cauchy relation is satisfied at least very closely by all the salts, and there is no reason to think that it may not be satisfied within a considerably smaller margin than the error of these experiments. As a first approximation, the assumption of the Cauchy relation seems to be justified.

Although the theory is thus justified as far as the Cauchy relation goes, it is still very far from complete. A complete theory would allow a detailed calculation of the numerical values of all three moduli. This it was not able to do in the case of NaCl, and the situation is not altered now by the determination of these new constants. In fact, the situation has become somewhat more complex, because although there is a certain regularity in the progression of the compressibility in passing from one alkali halide to another, and there is also a regularity in s_{11}, there is no such regularity in s_{12} and s_{44}, whereas some sort of regularity would doubtless be given by any first simple theory.

Summarizing, the three elastic moduli of KI, KBr, KCl, NaBr, and NaCl have been determined, and the compressibility of an artificial crystal of NaCl measured to 12000 kg/cm^2. The Cauchy relation between the elastic moduli is found to be satisfied, thus checking the expectation from Born's theory of crystal lattices, now put on a firmer basis by the new wave mechanics. There is, however, no theory which gives the exact numerical values of the moduli; there are irregularities in the sequence of the moduli which will probably be difficult for a simple theory.

It is a pleasure to acknowledge the skillful assistance of Mr. George Langreth in the manipulations of producing the single crystals. I am also much indebted for financial assistance to the Milton Fund of Harvard University.

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THE EFFECT OF PRESSURE ON THE RIGIDITY OF SEVERAL METALS.

By P. W. Bridgman.

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Introduction.

Determinations have already been published of the effect of pressure on the rigidity of several varieties of glass.[1] The experimental method which was finally developed to make those measurements was just as capable of dealing with metals as with glass, and since the measurements on metals have a greater intrinsic interest than those on a substance of variable composition like glass, the method would have been applied in the first instance to metals, had not the complete preparations already been made for the measurements on glass, due to an erroneous preconception as to the relative magnitudes of the effect in metal and glass. In this paper the method is applied to eight metals up to 12000 kg/cm^2.

Method.

The method is essentially the same as that of the previous work. It is a differential method; two helical springs are stretched against each other, one spring consisting of the metal on which the effect is to be determined, and the other spring being of some standard metal on which the effect has already been determined by some absolute method. The standard metal was steel cut from the same spool of wire as the steel of the previous paper, and the absolute effect on it was determined by the method described in that paper, and in fact the actual value there found was used, making no new experimental determination. The two helical springs are coupled through a short length of manganin wire, sliding over an insulated contact attached to the same frame which maintains the springs stretched. If there is a change in the relative stiffness of the two springs when hydrostatic pressure is applied, there will be a motion of the point of coupling which can be measured by determining the change in the potential drop between the contact fixed to the frame and another contact attached to the wire, a current flowing lengthwise of the manganin wire.

The experimental arrangements were practically the same as in the previous paper. The apparatus was essentially like that shown in Figure 1 of that paper, except that the sliding contact was now located in the middle of the frame, so that the two springs were of equal length, this being the disposition to give maximum sensitiveness. The dimensions of the springs were so adjusted that the stiffness of the two springs should be the same, this condition being demanded by maximum sensitiveness. The pressure part of the apparatus was the same as before; the springs were mounted in the same cylinder as before, and were rotated as before to secure freedom from friction.

The method of applying the corrections and calculating the change in rigidity from the measured changes on the potentiometer was improved and simplified as compared with that used in the previous paper. The fundamental formula for the spring was taken as before to be:

$$P = \tfrac{1}{2}\pi \frac{a^4 \mu \varphi_0^2}{s^3 \cos^2 \alpha} (l - l'),$$

where P is the stretching load, a the radius of the wire of which the spring is wound, μ the rigidity of the material of the wire, l the stretched length and l' the unstretched length of the *helical* part of the spring, s the total length of wire in the helical part, α the angle between the turns of the helix and a plane perpendicular to the axis, and φ_0 the total angle through which one end of the helix is rotated compared with the other. When there are two springs stretched against each other, P for the two springs is the same, and may be eliminated from the two equations for the two springs. Also when pressure is applied, and there is a shift of the position of the coupling point, the same equality continues to hold, the values of a, μ, l, etc. on the right hand side being now the values under pressure. The effect of pressure on all the terms on the right hand side can be written out in terms of the geometry, known compressibilities, and the change under pressure of *l* given by the potentiometer measurements, except for the changes under pressure of the rigidity, which remains in the equation as unknown. If the pressure coefficient of one of the rigidities is known, as that of the steel spring by independent experiment, the other may be calculated from the equation in terms of known quantities. In the equation above, φ_0 is to be taken as not changing under pressure, the original spring being in a state of ease and so stretching without twist.

The equations actually used in the computations are:

$$(1-\chi_1 p)\left(1+\frac{d\mu_1}{\mu_1}\right)\left[1+\frac{\cos 2\alpha_1}{2\cos^2\alpha_1}\left(\frac{dl_1}{l_1}+\chi_1 p\right)\right]\left[1+\frac{dl_1+l_1'\chi_1 p}{l_1-l_1'}\right]$$

$$=(1-\chi_2 p)\left(1+\frac{d\mu_2}{\mu_2}\right)\left[1+\frac{\cos 2\alpha_2}{2\cos^2\alpha_2}\left(\frac{dl_2}{l_2}+\chi_2 p\right)\right]\left[1+\frac{dl_2+l_2'\chi_2 p}{l_2-l_2'}\right],$$

$$dl_1 = -\frac{\Delta R_0}{\rho_0}+\frac{\alpha p}{\rho_0}(R_0+\Delta R_0)+p\,[\lambda_1\chi_1+l_4\chi_3-L_0\chi_4],$$

$$dl_2 = -\,dl_1+p\,[\lambda_1\chi_1+\lambda_2\chi_2+l_3\chi_3-L\chi_4].$$

The meaning of most of the letters used in the formulas is obvious from figure 1. λ_1 and λ_2 are the lengths of the non-helical parts

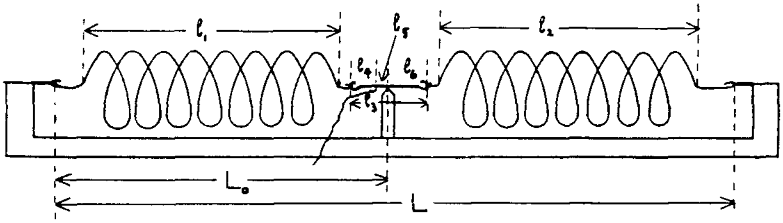

FIGURE 1. Scheme of the apparatus for measuring the effect of pressure on the relative rigidity of two different metals.

of the springs, that is, the lengths along the axis of the hooks on the two ends by which attachments were made. The various χ's denote the linear compressibilities of the various parts of the apparatus, taken as intrinsically positive. χ_1 is the linear compressibility of the metal to be measured, the length of the helical part of the spring of which is l_1, χ_2 is the linear compressibility of the comparison spring of piano wire, χ_3 that of the manganin connecting wire, and χ_4 that of the supporting frame of mild steel. α is the pressure coefficient of resistance of the manganin per unit length. α is obtained from a measurement of the pressure coefficient with the terminals rigidly attached combined with the linear compressibility. In the following, $\Delta R_o/\rho_o$ will be referred to as the uncorrected value of the elongation.

The advantage of the formulas in the form given is that the stiffness of the individual springs does not enter, and no experimental determination of the amount of stretch of each spring under known weights at atmospheric pressure is necessary. The formulas of the previous paper did involve this stiffness, which was determined by direct experiment. The formulas used there were more complicated, and the stiffness appeared in two places. It now appears that the stiffness cancelled from the final result, a fact which evidently would have much simplified the previous calculations if I had noticed it in time. A second advantage of the formulas in the new form is that the measurements obviously give differential results. The difference between the pressure coefficients of the rigidities of tungsten and platinum, for example, is correct whether the value used for steel is in error or not, and if at any future time it should appear that the value used for steel was in error, the values given here can be corrected by adding the same correction to them all.

There follows now the detailed presentation of data.

DETAILED DATA.

In general comment on the substances chosen for investigation in the following it would appear that a number of rather uncommon metals have been included. The reason for this is in the limitations of the method. The metal has to be one which when drawn into wire and wound into a helical spring will permit a fair amount of stretch without assuming permanent set. There are not a great many metals which satisfy this requirement, and in the following I have measured all such that were readily available. The requirement of high elastic limit rules out a number of the common metals such as gold, silver, and copper.

Tantalum. This is the only metal for which more than one set of measurements was made, so that from this some idea may be obtained of the probable accuracy and significance of the results. The wire I owe to the kindness of the Research Laboratory of the General

Electric Co. at Schenectady, who supplied it to me from their regular stock. It was not very uniform in geometrical shape, the external diameter varying from 0.0223 to 0.0239 cm. Three sets of measurements were made; two of these were with the identical steel and tantalum springs, one measurement being made near the beginning of the series, and the other near the end. The purpose of the repetition was to determine the probable error due to the apparatus in measurements on the same metal. The third measurement was made on steel and tantalum springs of different dimensions from the first, and the agreement of this result with the two others will give some idea of the significance of these measurements as determining absolute constants of the metals, unaffected by accidental differences in different samples.

All the measurements of this paper on the different metals are much more irregular than measurements of most other pressure effects; in particular there is much greater tendency for a few points in each run to lie very far off the curve. There is sometimes a distinct tendency for the points to lie on one or the other of two distinct lines, the appearance being as if the springs were capable of assuming one or the other of two positions of equilibrium. The explanation of this may be found in the slight rotary motion sometimes possible to the springs due to their manner of suspension. It must be remembered that the conditions here are very much more severe than in the usual pressure experiment, the apparatus being rotated and the contact purposely broken and made several times before each reading. Perfect readings demand that the contact assume a definite unique position at each pressure, irrespective of the number of times it has been made or broken. Slight particles of dirt in the transmitting medium, which are almost impossible to avoid, produce an effect, and this is doubtless the explanation of the few points with exceptionally large discrepancies.

Of the three runs with tantalum, the first was the best. Eleven readings were made to 12000 kg/cm^2. Of these two were discarded; the remaining nine lay on a straight line with an average departure from it by a single point of 6%. The corrections were of such a magnitude as to reduce the "uncorrected" value for the shortening of the tantalum spring to a final value about one-half as large. The actual shortening under 10000 kg was 0.0034 cm. On the repetition of the experiment several months afterwards, thirteen measurements were made. Two of these had to be discarded; the remainder lay on two straight lines of the same slope, the distance between the lines being one-third of the maximum effect. The average departure of a single reading from one or the other of these two lines was 3.3% of the maximum effect. The first set-up gave, after all corrections, an increase of rigidity of 1.49% for 10000 kg, and the repetition an increase of 1.65%. The first result is to be preferred. The run with the second set of springs gave an opposite sign for the uncorrected effect. Thirteen readings were made to 12000 kg, of which three had to be discarded, the best of them lying off the curve by 30%. The average departure from a straight line of a single one of the remaining readings was 5.4% of the maximum effect. The finally corrected result was an increase of rigidity under 10000 kg of 0.31%, about one-fifth of that found with the first springs. The determinations with the second springs are not so good as with the first, as shown by the greater irregularity of the experimental points, and the fact that the relative stiffness of the tantalum and the steel spring was not so well adjusted to give the maximum sensitiveness. Nevertheless there can be no question, I think, that all the difference between the results with the two samples cannot be ascribed to experimental error, but the two springs were doubtless actually different in their behavior under pressure. This is not so surprising when it is considered that in a drawn wire there are many internal strains, which may have been particularly great in this wire, as suggested by the lack of uniformity in the diameter.

The conclusion to be drawn from these measurements is that the rigidity of homogeneous tantalum increases under pressure by something of the order of 1% for 10000 kg.

Molybdenum. This wire I also owe to the stock of the General Electric Co. It was not perfectly round, but varied in diameter from 0.0261 to 0.0270 cm. One successful run was made to 12000 kg; several unsuccessful attempts were first made, in which there was one trouble or another with the connections and contacts. Ten readings were made in the successful run; these were best represented by a straight line, but the departures of some of the points were rather large. The average departure from a line of a single reading (no discards) was 19% of the maximum effect. The independent correction terms were nearly as large as the uncorrected elongation, but there are both positive and negative corrections, so that the final corrected elongation differs by only 2% from the uncorrected value.

The final result is an increase of rigidity of .15% under 10000 kg.

Tungsten. This was also obtained from the General Electric Co. in the form of wire 0.025 cm in diameter. Readings were made on two days with the same set-up, and three excursions were made to 12000; a number of the single pressure settings gave no readings at all, doubtless because of dirt preventing contact. Twelve readings with positive contacts were obtained; two of these were discarded, the better of them lying off a line by 40% of the maximum effect. The average departure from a straight line of the remaining 10 points was 7% of the maximum effect. The corrections, of which the largest is more than three times the uncorrected effect, combine in such a way as to make the final corrected elongation somewhat more than twice the uncorrected elongation.

The final result was decrease of rigidity of 0.29% under 10000 kg. This unexpected negative result is probably connected with the lack of perfect homogeneity of wire of this metal; when an ordinary tungsten wire is broken by repeated bending it frequently splits, in the neighborhood of the bend, into several long fibres.

Platinum. This was Baker's purest platinum, annealed, 0.0294 cm in diameter. One set-up of the apparatus was used, and readings made to 12000, back to 3000, and up to 9000 again to check at doubtful points. Eight readings in all were obtained with steady contacts. Of these two were discarded, the better lying off the line by 50%. The average departure from a straight line of a single one of the remaining 6 points was 2.6% of the maximum effect. One of the correction terms is 25% larger than the uncorrected displacement; the final corrected displacement is 11% less than the uncorrected displacement.

The final result is an increase of rigidity of 2.4% for 10000 kg.

Zirconium. This material I owe to the kindness of Dr. G. Holst of the Philips Lamp Works at Eindhoven, Holland. It is from the same length of wire as that on which I have already determined the pressure coefficient of resistance.[2] The wire was very uniform and 0.050 cm in diameter. The spring also wound much more uniformly than many of the other metals, indicating probable absence of internal strains. One set-up was used, with two excursions to 12000, making eight readings. Discarding none of these, the average departure of a single reading from a straight line was 5.5% of the maximum effect. Of these eight points, the three worst were at pressures below 4000 kg; the average departure of a single one of the five readings above 4000 was 1.9% of the maximum effect. One of the correction terms was 66% larger than the uncorrected effect; all of the corrections combined in such a way as to make the final corrected displacement 10% less than the uncorrected displacement.

The final result was a decrease of rigidity of 0.17% for 10000 kg.

Palladium. The material was from Baker and Co., annealed wire, 0.029 cm in diameter. The results on this metal are by far the most unsatisfactory of all, and must be taken as merely of orienting value. The reason is the low elastic limit. The original spring, when stretched against the steel spring, was not far from its elastic limit, and under pressure there was an effect which amounted to an increase of set or lowering of the elastic limit. Two excursions to 12000 were made; the up and down points of the two runs lay on four straight lines like a distorted Greek sigma, the change in slope corresponding to a decrease in stiffness of the spring. After the termination of the experiment, the palladium spring was found to have received a considerable permanent elongation.

The effect of pressure on the elastic limit has apparently never been determined; what we have here is virtually a qualitative observation that the limit is lowered by pressure, an unexpected result.

Making due allowance for the effect of permanent set, the individual points of this set of measurements with palladium were perhaps better than those with any other metal, the individual points, except for one discard, lying off the straight lines by only 1 or 2%. In making the calculations, the mean of the first up and down excursion was used, as representing best the virgin wire. One of the correction terms is nearly twice the uncorrected term. The corrections combine in such a way that the final corrected displacement is of the opposite sign from and only 3% of the measured effect. That is, the corrections together almost exactly balance the measured effect.

The final result is an increase of rigidity of 1.08 % for 10000 kg.

Nickel. This was "pure" nickel from Baker and Co., 0.025 cm in diameter. A single run was made to 12000 and back, making seven readings. No points were discarded; the average departure of a single reading from a straight line was 5.7% of the maximum effect. The largest of the correction terms was 50% larger than the measured effect; the final corrected displacement was 30% less than the uncorrected displacement.

The final result is an increase of rigidity of 1.84% for 10000 kg.

Thorium. This was from the same piece of wire whose pressure coefficient of resistance I have measured,[3] and which I owe to the kindness of Dr. Rentschler of the Westinghouse Lamp Works. The section of the wire was far from regular, it was more nearly rectangular in section than either circular or elliptical, and the maximum and minimum diameters were 0.033 and 0.039 cm. Two excursions were made to 12000, obtaining 24 readings; of these 6 had to be discarded, the best departing from a straight line by 20% of the maximum effect. Of the 18 remaining readings, 12 lay on one line and 6 on another of the same slope, the average departure of a single reading from one or the other of these lines being 4.4%. The effect is unusually large, the largest correction term is only about one-half the uncorrected term, and the final corrected displacement is 54% of the uncorrected displacement and of the same sign.

The final result is an increase of rigidity of 5.73 % for 10000 kg.

DISCUSSION.

Not a great deal of significance can be attached to the exact values found above for the pressure coefficient of the shearing modulus, as shown by the failure to obtain the same results on two springs of tantalum. One reason for this has already been suggested in the internal strains always found in any drawn wire; the importance of such strains was shown strikingly enough in the historic struggle between the multi- and the rari- constant theories of elasticity. Furthermore, the pressure coefficient of rigidity is not so definite a thing physically as the pressure coefficient of the compression modulus, for example. For a cubic crystal is equally compressed in all directions by hydrostatic pressure, and the compressibility of an aggregate is determined merely by the compressibility of the individual grains, and is independent of their relative orientations, whereas the rigidity of a microscopic aggregate of cubic crystals is connected in a more complicated way with the three elastic constants of the individual crystal grains, and will vary accordingly as the arrangement of the individual crystals is completely random or has traces of order. All of this makes it evident that the results above have a statistical rather than an individual signifficance.

In the following table are collected the values found above for the effect of 10000 kg on the rigidity, together with the value previously found for the percentage effect of the same pressure on the incompressibility.[4] This latter is defined as $(2b/a)10^4$, where the

a and the b are the constants in the formula for the change of volume under pressure: $\Delta V/V_0 = -ap + bp^2$, p being in kg/cm^2.

TABLE I.

SUMMARY OF THE EFFECT OF PRESSURE ON ELASTIC BEHAVIOR.

Metal.	Percentage Change of Rigidity under 10,000 kg/cm².	Percentage Change of Incompressibility under 10,000 kg/cm².
W	— .3	+ 8.8
Ta	+ 0.3 to + 1.5	+ 1.1
Mo	+ .15	+ 6.9
Zr	— .17	+ 13.6
Pt	+ 2.4	+ 10.
Th	+ 5.7	+ 28.4
Pd	+ 1.1	+ 8.1
Ni	+ 1.8	+ 7.9
Fe* (steel)	+ 2.2	+ 7.2

* Previous Result

With the exception of tungsten and zirconium, for which the effect is small, the rigidity increases under pressure. An increase is what would be expected from general considerations, and is to be contrasted with the decrease shown by several varieties of glass.

Further, the increase of rigidity under pressure is notably less than the increase of incompressibility. This again is what might be expected, and is doubtless connected with the very rapid increase in the force of repulsion between atoms when they are brought closer together than their normal distance of separation. The forces resisting volume compression are for the most part contributed by the pairs of atoms in closest contact. The repulsion between these increases rapidly when the distance between them is made less, so that the compressibility decreases by a comparatively large amount as the volume decreases under increased pressure. The forces resisting shear, on the other hand, contain a larger contribution from the more distant atoms, the component of the force effective in resisting shear contributed by the atoms directly in contact being of the second order. But the forces between distant pairs of atoms do not increase with decreasing distance as rapidly as those between adjacent pairs, and hence the effect of decrease of volume (or of increase of pressure) must be less on rigidity than on incompressibility.

The formulas have been given in the previous paper on the rigidity of glass for the effect of pressure on Young's modulus in terms of the effect on compressibility and rigidity. It will be found in general that for the metals studied above Young's modulus increases under pressure by an amount intermediate between that of the rigidity and the incompressibility. This seems natural in the light of considerations on the nature of the atomic forces like those of the last paragraph.

I am much indebted to my assistant Mr. W. A. Zisman for making the readings and setting up the apparatus. I am also indebted to the Milton Fund of Harvard University for financial assistance.

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[2] P. W. Bridgman, Proc. Amer. Acad. 63, 347, 1928.

[3] P. W. Bridgman, Proc. Amer. Acad. 62, 217, 1927.

[4] P. W. Bridgman, Proc. Amer. Acad. 58, 166, 1923, in addition to references 1, 2, and 3.

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THE COMPRESSIBILITY AND PRESSURE COEFFICIENT OF RESISTANCE OF SEVERAL ELEMENTS AND SINGLE CRYSTALS.

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INTRODUCTION.

This paper is in continuation of my program of determining the quantities indicated in the title for all the well defined materials possible, particularly elements and single crystals.[1] The novel feature in this paper is that there are included measurements of the linear compressibility in different directions of single crystals of several organic substances, a class of substance for which these measurements have not hitherto been made. This has demanded the construction of a new type of piezometer, the former type not being applicable because in it pressure is transmitted directly to the specimen by kerosene, in which most organic substances dissolve.

Apparatus and Method.

The design of the new piezometer is indicated in Figure 1. The specimen is submerged in mercury, by which pressure is transmitted to it. The specimen under pressure is connected to a manganin wire, held pressed tightly against it by a spring, the wire sliding over a fixed contact, so that the change of dimensions of the specimen under pressure can be determined in terms of resistance measurements on a potientometer, exactly as in the previous types of piezometer. Corrections must be applied to the readings, similar in character to the corrections demanded by the other forms of piezometer, for the linear compressibility of the steel parts, the linear compressibility of the manganin wire, and the change of specific

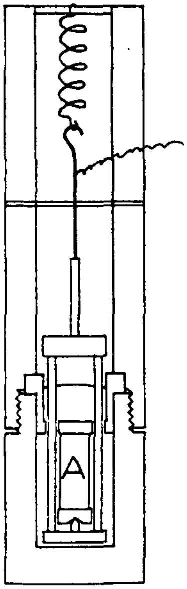

Figure 1. Diagram of the new form of piezometer, in which the specimen, A, is submerged under mercury to prevent action between the kerosene by which pressure is transmitted and the specimen.

resistance of the manganin under pressure. These corrections have been determined by direct and indirect measurement. In addition to these corrections which can be calculated, there are other corrections arising from small effects which cannot be determined so easily, such for example, as that arising from the compressibility of the insulating washers of mica, or from internal strains in the metal parts at the various screw connections. These corrections were determined together by measuring with the apparatus the compressibility of pure iron, the compressibility of which is already known, and finding the corrections which must be added to the calculated corrections to give the known compressibility. These corrections altogether amounted to a change of length of about 0.002 cm at 10000 kg/cm^2.

It will be noticed that in this apparatus the changes of dimensions are measured directly, without multiplication as in the previous piezometer. The necessity for this arose from the fact that many organic substances are too weak mechanically to withstand the stress to which they must be subjected in the multiplying apparatus. In using the piezometer, small specimens had to be measured in a number of cases, because it is often difficult to obtain crystals of organic substances of any size. In consequence of these two facts, the measured effects were often small, and the corrections were sometimes as much as 50% of the measured effect. The accuracy with this type of apparatus is not as high as that obtainable with the previous types, which still are to be used whenever the substance will allow it.

There follows now the detailed description of the various measurements.

Effect of Pressure on Electrical Resistance.

Indium. This material was of exceptionally high purity, having been made by Professor T. W. Richards in connection with determinations of its atomic weight. I owe my supply to the kindness of Dr. L. H. Hall, to whom was intrusted the task of winding up many of the scientific affairs of Professor Richards after his death.

The potentiometer method of measurement was used. The wire, of about 0.035 cm diameter, was made by cold extrusion through steel dies. The piece measured was about 10 cm. long, bent into a hair pin shape. The terminals were fine wires of pure silver, fused directly to the indium by a simply constructed arrangement utilizing the Joulean heating of a current through the silver. The use of solder in attaching the terminals was undesirable because indium forms with tin and lead an alloy of melting point lower than 75°, at which it was desired to make measurements.

Measurements of the effect of pressure on resistance were made in the regular way up to 12000 kg at 30° and 75°. The pressure measurements went very smoothly; the mean departure of a single point from a smooth curve at 30° being 0.09% of the maximum effect, and at 75° 0.03%. The relation between change of resistance and pressure is very nearly of the second degree, but departs from it by more than the experimental error, the pressure of maximum departure from linearity being somewhat less than the mean pressure. The accompanying table gives the effect at pressure intervals of 2000 kg. The initial resistances at atmospheric pressure at 30° and 75° were 1.1472 and 1.3678 respectively, in terms of the resistance at 0°.

TABLE I.

THE RESISTANCE OF INDIUM UNDER PRESSURE.

Pressure Kg/cm²	$\frac{-\Delta R}{R(0, 30^\circ)}$	$\frac{-\Delta R}{R(0.75^\circ)}$
2000	.0288	.0302
4000	.0549	.0575
6000	.0795	.0831
8000	.1026	.1075
10000	.1245	.1295
12000	.1450	.1504

The temperature coefficient of resistance at atmospheric pressure between 0° and 100°, obtained by linear extrapolation of actual readings at 25° and 75°, was 0.004904. By combining with the values in the table for the effect of pressure, the corresponding temperature coefficient at 12000 is found to be 0.004876, thus agreeing with the result found for many other metals that the temperature coefficient is little affected by pressure.

I have previously measured the effect of pressure on the resistance of a sample of indium of inferior purity.[2] The mean coefficient to 12000 of the pure metal is about 15% greater than that of the former sample, agreeing with the universal rule that the coefficient of the purer metal is less algebraically than that of its alloys. The temperature coefficient of the former sample was 0.00404, against the value 0.00490 for this new pure material. The new value is higher than any listed value of the temperature coefficient.

Manganese. This material I owe to the kindness of Professor M. A. Hunter of Rensselaer Polytechnic Institute, who prepared it in massive form by electrolysis of the fused salts. The specimen on which the resistance measurements were made was in the form of wire several cm long and of the order of 0.5 mm in diameter. It was most kindly prepared from the massive material by Mr. G. F. Taylor of the General Electric Co. at Schenectady by his method of drawing out a tube of glass or quartz containing the metal heated above its melting point.

Manganese is a metal which previous investigators have found very difficult to get into massive form without the formation of numerous cracks which destroy the continuity of the metal. These cracks have been attributed to a polymorphic transition which manganese passes through on cooling from the melting point to room temperature. The transition is accompanied by a large change of volume. It would be expected that this difficulty would make impossible the formation of wire by the Taylor process. Doubtless the effect was present, for although the quartz capillaries in which the magnanese was drawn out were 10 or 15 cm long, and they were apparently completely filled with a thread of manganese, the thread always broke into lengths varying from a few millimeters to one or two centimeters. These short lengths were very strong mechanically, being very difficult to break with the fingers, and not showing any of the brittleness usually associated with metallic manganese. The places in which the thread broke doubtless corresponded to the cracks usually found in the massive metal. It is possible that the coherent pieces may have been single crystals of the low temperature modification.

Measurements of resistance were made by the potentiometer method. Four terminals were attached to the specimen by springs. It was not until after the completion of the measurements that I was informed by Mr. Taylor, and verified for myself, that it is very easy to solder manganese with soft solder; if I had known this in time, I would have soldered the connections, instead of using springs, because of the greater convenience.

Before making the pressure measurements, the temperature coefficient of resistance was determined at atmospheric pressure. The mean coefficient between 0° and 100°, obtained by linear extrapolation of measurements at 25° and 75°, was 0.00078. There seem to be no published values of this coefficient, but 0.00079 is so much lower than the value customary for a pure metal that there can be little doubt that the metal contains several per cent of impurity. It is perhaps more probable that the impurity was in the original material than that it was given to it during the process of formation into wire.

In view of the probable impurity, the effect of pressure was measured only at 30°, up to 12000. The points lay smoothly, the average deviation of a single reading from a smooth curve being 0.1%. The relation between change of resistance and pressure can be represented within experimental error by a second degree formula:

$$\Delta R/R_0 = -7.012 \times 10^{-6}p + 5.63 \times 10^{-11}p^2.$$

It is thus seen that the resistance decreases with increasing pressure, as is normal, and the curvature is also in the normal direction. Perfectly pure manganese, in accordance with the universal rule, may be expected to have a negative coefficient somewhat larger numerically than the value above.

Chromium. The material was obtained from Eimer and Amend. It had been made by the Goldschmidt process, was quite brittle, and probably had several per cent of impurity. It was very kindly made into wire for the pressure measurements by Mr. Taylor by his method. More difficulty was experienced with this than with manganese, the particular difficulty being sticking of the metal to the quartz tube in which it was drawn out. Removal of the quartz with hydro-fluoric acid was not as successful as with some other metals, and the method finally used was mechanical, breaking away as much of the quartz as possible, and removing the remainder by rubbing with emery paper. The dimensions were about the same as for manganese. There is not the difficulty with chromium from a polymorphic transition that there is with manganese, but its greater brittleness makes the manipulation more difficult.

The potentiometer method of measurement was used. It is not possible to solder chromium with either soft solder or silver or gold. The four terminals were fine platinum wires attached by spot welding; I am much indebted to Dr. H. G. deLászló of the Mass. Inst. of Technology for very skillfully doing this.

At atmospheric pressure the temperature coefficient of resistance between 0° and 100° was found to be 0.000033. This is very low indeed, and indicates high probable impurity. The specific resistance at 30° was 160×10^{-6}, very high, and also suggestive of impurity.

At 30°, resistance decreases linearly with pressure up to 12000, the pressure coefficient being -5.8×10^{-7}. This is very small, but of the normal sign. The pure metal may also be expected to have the same negative sign, but to be considerably larger numerically. Considering the smallness of the effect, the readings were very regular, the average deviation of a single reading from a straight line corresponding to 0.12 mm on the slide wire of the potentiometer; this is equivalent to 1.7% of the maximum change of resistance.

Arsenic. See the next section for a description of the effect of pressure on the electrical resistance.

COMPRESSIBILITY.

Arsenic. Since the measurements of resistance under pressure and of compressibility of this element were closely related, it is best to describe them together. These results are to be regarded only as preliminary; it is evident that arsenic is highly crystalline in its properties, and the final study must be made on single crystals.

The material was from Kahlbaum, grade "K." The compressibility was determined first. I tried to make a single crystal by sealing the arsenic in a heavy quartz capillary of about 2 mm inside diameter, and slowly lowering from an electric furnace maintained above the temperature of the triple point. This attempt to make a single crystal was not successful, but nevertheless the resulting material was highly crystalline in appearance, and there was a strongly marked preferred direction of orientation. The appearance was much like that which I have often found in trying to make single crystals of tellurium by slow cooling; the cleavage planes are usually parallel to the axis of the rod, but the orientation about the axis is at random. In the case of tellurium, more rapid cooling and higher purity in the original material brings the desired result. It is possible that the arsenic may have been contaminated by the quartz during this attempt, since the inside of the capillary was somewhat pitted after the run, which lasted for 15 hours.

The compressibility of this approximately single grain was measured in the regular way with the lever piezometer for short specimens. Two runs were made to 12000 at 30°. The results of the first run were much more irregular than usual, and showed the highly unusual feature of an abnormal curvature, that is, a compressibility increasing with increasing pressure. The second run, made more carefully, showed that the abnormal curvature was illusory; the curve really consists of two parts with a discontinuity between 6000 and 8000 kg, the slope of the low pressure branch being less than that of the high pressure branch. The explanation clearly is a polymorphic transition. It is an unusual feature of this transition that the points corresponding to the low pressure modification could be repeated after the excursion into the domain of the high pressure modification, indicating that the low pressure modification recovers its original orientation. The high pressure modification is therefore probably not formed by the chance occurrence of a nucleus and growth from it at random, but there is some definite relation between the lattices of the two modifications such as is shown, for example, by quartz.

The initial linear compressibility of the low pressure modification was 2.2×10^{-7}, giving for the volume compressibility 6.6×10^{-7} on the assumption of equal compressibility in all directions. The volume compressibility of arsenic at low pressures has been directly determined by Richards[3] to be 4.4×10^{-6}. This great discrepancy cannot possibly be due to experimental error, but must mean that the compressibility of a single arsenic crystal is very different in different directions.

The linear compressibility of the high pressure modification was 2.3×10^{-7}, slightly higher than that of the low pressure modification, but the exact significance of this result cannot be clear until the relative orientation of the two phases is known.

In order to investigate more accurately the transition phenomena, the resistance under pressure of arsenic was measured. For the resistance measurements the arsenic was cast in quartz in the form of a rod several centimeters long and about 1 mm in diameter. The procedure in making the casting was so much like that described by Kapitza[4] in a paper published after this work was done that it is not necessary for me to add anything in the way of description. I also observed the fluorescence of the arsenic vapor in the tube, but I would describe the color as greenish yellow rather than as reddish yellow. My rod was not a single crystal grain like that of Kapitza. The production of the casting required only a few minutes, instead of many hours as before, and there was no pitting of the inside of the quartz capillary. The high purity of this arsenic was verified by measuring its temperature coefficient of resistance at atmospheric pressure. The mean coefficient between 0° and 100°, obtained by linear extrapolation of readings at 30° and 75°, was found to be 0.00474 immediately before the casting had been subjected to pressure, and 0.00472 after several exposures to pressure and the consequent formation of the high pressure modification. This is considerably higher than any listed value for the temperature coefficient.

The pressure measurements of resistance were made in the regular way with the potentiometer; the leads were fine silver wire attached with soft solder. Special pains was taken to get the initial effect on the virgin specimen at low pressures before the transition had occurred. Points were thus obtained on a smooth curve, the resistance *increasing* with increasing pressure. A discontinuity occurred with increase of pressure between 5050 and 6030 kg. The accidental breaking of one of the connections at the maximum pressure prevented measurements of the change of resistance with decreasing pressure. On the next application of pressure the effect on the low pressure modification had changed sign, the resistance now decreasing, with the coefficient -1.52×10^{-6}. A discontinuity was again found with increase of resistance, this time in the neighborhood of 5500 kg. On decreasing pressure an enormous hysteresis was found in the resistance of the high pressure modification, but the discontinuity was at essentially the same place as before, and the pressure coefficient of the low pressure modification was not much altered.

A second piece of arsenic was tried. Trouble with the connections made it impossible to get readings on the virgin specimen. The second application of pressure gave a pressure coefficient of resistance of -1.58×10^{-6} for the low pressure modification, and a discontinuity between 5400 and 5800. The behavior on releasing pressure was approximately the same as before; very great hysteresis in the resistance of the high pressure modification, and a discontinuity, now a little more pronounced than before, at approximately the same pressure, and again approximately the same pressure coefficient for the low pressure modification.

The best value for the transition pressure from the resistance measurements is 5500 kg, somewhat lower than the lower limit found from the compressibility measurements.

These results obtained with arsenic may be summarized as follows. There is a new modification at high pressures, and the transition pressure at 30° is in the neighborhood of 5500 kg. The compressibility of single crystal arsenic must vary greatly with the direction in the crystal, there being a direction in which the compressibility is at least 6.7 times greater than the average. The temperature coefficient of resistance at atmospheric pressure between 0° and 100° is 0.00473. There are several obscure points; why the great hysteresis in the resistance of the high pressure modification, why the difference in the transition pressures from the compressibility and the resistance measurements, and why the positive pressure coefficient of resistance on the virgin specimen, and a nearly constant value of -1.5×10^{-6} on the same material after it has experienced the transition.

The behavior of arsenic has been previously measured under pressure.[5] The previous specimen was very impure, the temperature coefficient of resistance being only 0.00076. The resistance was found to have a pressure coefficient of -3.3×10^{-6}. There was considerable irregularity in the previous results, which was not inconsistent with a transition.

Boron. The specimen was a rod about 1 cm long and 1.5 mm in diameter. It was most kindly loaned to me for these measurements by Mr. Alfred Loomis of Tuxedo Park, who had obtained it from Dr. G. Holst of Eindhoven. It was prepared by the method developed there by van Arkel of thermal decomposition of the vapor of BCl_3 and BBr_3. It is deposited from the vapor on a core of tungsten wire. The diameter of this wire is of the order of 0.05 mm, making the total impurity of tungsten about 0.1%. Except for this, the material may be expected to be very pure.

The measurements were made with the lever piezometer for short specimens. The shape of the piece of boron was not as regular as would have been desirable; it could not be made to fit the piezometer as well as usual, and the results were much more irregular. Another source of irregularity was the smallness of the effect, because the compressibility of boron is very nearly the same as that of iron. The average departure of a single reading from a smooth curve (which within the limits of error was taken as a straight line) was 6.9% of the maximum measured effect, that is, 6.9% of the difference of compressibility between boron and iron. This means an irregularity of only 0.46% on the actual compressibility, but this is considerably greater than the irregularity usual wuth other substances. In view of the irregularity in the measurements, no attempt was made to find the temperature coefficient of compressibility, and measurements were made only at 30°. The results found for the linear compressibility were:

$$-\Delta l/l_0 = 1.837 \times 10^{-7}p - 0.70 \times 10^{-12}p^2.$$

Assuming equal compressibility in all direction, this gives for the volume compressibility:

$$-\Delta V/V_0 = 5.51 \times 10^{-7}p - 2.2 \times 10^{-12}p^2.$$

The second degree terms in these expressions is contributed entirely by the iron. According to this boron is about 6% less compressible than iron.

The crystal system of boron has not been determined, so that this result does not have as much significance as it might, Richards[7] found for the volume compressibility 3×10^{-7} on a specimen known to be of high impurity. If boron turns out to have cubic symmetry, the entire difference between the result of Richards and myself must be ascribed to difference of purity; if not, part of the difference may well be due to the crystal structure. A value somewhat between 5.5 and 3 would fit into the periodic system of the elements better than either. It seems to me probable that boron will be found to be not of the cubic system and that its volume compressibility will be somewhat less than 5.5×10^{-7}.

Titanium. I am indebted for this material to Professor M. A. Hunter, who prepared small coherent slugs of the massive metal by electrolysis of fused salts. The compressibility was measured with the lever piezometer for short specimens. The pieces measured were formed by grinding from the slugs resulting from the electrolysis; two of them were used piled together, of 1.5 and 1.1 cm length. Measurements were made to 12000 kg at 30° and 75°. Within the limits of error, a second degree expression in the pressure reproduces the results. At 30° the average departure of a single reading from a smooth curve was 1.1% of the maximum measured effect, which means 0.3% on the actual compressibility; at 75° the corresponding figures, discarding one reading, were 1.8% and 0.56%.

The crystal system of titanium is known to be hexagonal, with an axial ratio of 1.60. This is very close to the ratio for close packed spheres, so that it is probable that the compressibility of a single crystal of titanium is nearly the same in all directions. Furthermore, the method of preparation of the specimens would not lead to the expectation of any large crystal structure, with any particular direction of orientation preferred. It is therefore probably fairly safe to calculate the volume compressibility from the actual measurements of linear compressibility by assuming equal compressibility in all directions. The results found in this way are:

$$\text{At } 30^\circ \qquad -\Delta V/V_0 = 7.97 \times 10^{-7}p + 0.12 \times 10^{-12}p^2,$$

$$75^\circ \qquad -\Delta V/V_0 = 8.68 \times 10^{-7}p - 4.5 \times 10^{-12}p^2.$$

Two features of these results call for comment; the large increase of compressibility with temperature, and the fact that at 30° the direction of curvature is abnormal.

Apparently the compressibility of titanium has not been previously measured. The value 7.97×10^{-7} fits in well with its position in the periodic table.

Manganese. This material has been already described in connection with measurements of the effect of pressure on resistance. For the compressibility measurements two pieces were ground to the proper shape, of length 0.67 and 0.53 cm; these were then piled together and measured in the lever piezometer for short specimens. Measurements were made at 30° and 75° to 12000 kg. At 30° the average departure of a single reading from a smooth curve was 1.04% of the maximum measured effect, which means 0.27% on the actual compressibility; at 75° the corresponding figures were 1.12% and 0.30%. Both the high and low temperature modifications of manganese belong to the cubic system, so that the volume compressibility may be calculated from the linear compressibility assuming equal compressibility in all directions. The following results were found:

$$\text{At } 30^\circ \qquad -\Delta V/V_0 = 7.91 \times 10^{-7}p - 5.3 \times 10^{-12}p^2,$$

$$75^\circ \qquad -\Delta V/V_0 = 8.08 \times 10^{-7}p - 4.8 \times 10^{-12}p^2.$$

The only previous value is by Richards,[3] who found 8.4×10^{-7} as the average compressibility up to 500 kg. Both my value and that of Richards is very much out of line with what would be indicated by the neighbors of manganese in the periodic table; this would suggest a value not far from 5.6×10^{-7}.

Potassium Alum. } *Ammonia Alum.* } *Chrome Alum.* } These three alums were made in large single crystals by slow crystallization lasting several weeks from aqueous solution in a room held at constant temperature near 30°. The material was commercial C. P. The alums are cubic, so that a measurement of the linear compressibility in a single direction is sufficient to determine the cubic compressibility. Potassium alum was the first measured. Under high pressure there was some corrosive action between the alum and the steel parts with which it came in contact. In order to avoid this, the adjacent steel parts were gold plated. The compressibility of gold is so nearly the same as that of steel that no error can be introduced in this way. All measurements were made with the lever piezometer for short specimens. It was not possible to measure the chrome alum at 75° because of decomposition. The following are the results:

Potassium Alum.		Average Deviation of Single Reading from Smooth Curve.
At 30°	$-\Delta V/V_0 = 63.03 \times 10^{-7}p - 116.1 \times 10^{-12}p^2,$	.15%
At 75°	$-\Delta V/V_0 = 55.74 \times 10^{-7}p - 93.3 \times 10^{-12}p^2.$	.38%
Ammonia Alum.		
At 30°	$-\Delta V/V_0 = 63.54 \times 10^{-7}p - 102.3 \times 10^{-12}p^2,$	.63%
At 75°	$-\Delta V/V_0 = 61.98 \times 10^{-7}p - 100.8 \times 10^{-12}p^2.$	.45%
Chrome Alum.		
At 30°	$-\Delta V/V_0 = 64.86 \times 10^{-7}p - 112.5 \times 10^{-12}p^2.$	.48%

The compressibilities of these three alums are thus nearly the same. The most striking feature in the results is the very pronounced negative temperature coefficient of compressibility of potassium alum. The temperature coefficient of ammonia alum is also negative, but by a smaller amount. There are no previous values of the compressibilities of the alums for comparison.

Sodium Chlorate. This material crystallizes in the cubic system, so that a measurement of the linear compressibility in a single direction suffices. The crystal was prepared from the aqueous solution. The solution was maintained in a room at 30° for several weeks, and allowed to evaporate slowly. The source of material was commercial C. P. stock, obtained from a large chemical supply house; the slow crystallization should give a product of high purity. The compressibility sample was 0.61 cm. long, cut from a single crystal.

In the measurement of compressibility it was necessary to use the new piezometer for organic substances in which pressure is transmitted to the substance by mercury, not because $NaClO_3$ dissolves in kerosene, but because it combines with it explosively at pressures above 2000 kg, as I had previously found.

Measurements were made to 12000 at 30° and 75°, 14 observations at each temperature. At 30° the average departure of a single reading from a smooth curve was 1.3% of the maximum effect, and at 75° 1.5%. As already explained, the corrections with this method are much larger than with the lever piezometer; in this case the corrections amounted to 50% of the measured effect. The following are the numerical results, obtained immediately from the measurements, without adjustment:

At 30° $-\Delta l/l_0 = 1.765 \times 10^{-6}p - 3.78 \times 10^{-11}p^2,$

At 75° $-\Delta l/l_o = 1.633 \times 10^{-6}p - 1.92 \times 10^{-11}p^2.$

The results as given indicate a smaller initial compressibility at 75° than at 30°, which is abnormal, and also a smaller second degree term at 75°, which again is abnormal. The result of the combination of these two factors is that the average compressibility between 0 and 12000 kg is greater at 75° than at 30°, which is normal. A study of the relative magnitude of the errors of a single reading and of the departures from linearity will show that a great deal of significance cannot be attached to the second degree term. The best way to manipulate the results would seem to be to assume that the second degree term is the same at both temperatures and the average of those found, and then to so adjust the initial compressibility that when combined with the second degree term the average compressibility to 12000 kg found experimentally is reproduced at each temperature. In this way the following results were found, making the additional change from linear to volume compressibility. These are to be accepted as the most probable values on the basis of these measurements:

At 30° $-\Delta V/V_0 = 4.94 \times 10^{-6}p - 9.3 \times 10^{-11}p^2,$

At 75° $-\Delta V/V_0 = 5.28 \times 10^{-6}p - 9.3 \times 10^{-11}p^2.$

There seem to be no previous measurements of the compressibility of this substance for comparison.

Sodium Bromate. This was grown by slow evaporation from aqueous solution in a constant temperature room over a period of several weeks, like sodium chlorate. The original material was commercial stock, C. P.; the slow crystallization should have been effective in further purification. The sample for the compressibility measurement was cut from a single crystal and was 0.67 cm long. The compressibility was measured in the piezometer for organic substances, submerged under mercury. I did not verify by direct experiment that this spontaneously explodes on contact with kerosene at high pressures, but used at once the safe method without further inquiry.

Measurements were made to 12000 kg at 30°; a run was also made to 12000 at 75°, but there was evidently something the matter with the measurements, and on taking the apparatus apart, the sodium bromate was found to have completely decomposed, an effect not shown by the chlorate. At 30°, the two points at the lowest pressures lay off the smooth curves by amounts corresponding to about 1000 kg; the remaining points lay on a smooth curve with an average departure of 0.2% of the maximum effect. The dimensions and the magnitude of the effect were somewhat more favorable than in the case of the chlorate, so that the total correction was only 20% of the measured effect.

Sodium bromate is cubic, so that the cubic compressibility can at once be found from the linear compressibility in a single direction. The results were as follows:

At 30° $-\Delta V/V_0 = 4.320 \times 10^{-6}p - 7.42 \times 10^{-11}p^2.$

The compressibility is this somewhat less than that of the chlorate. This is not the direction of difference which one would at first expect, because the atom of bromine is by itself more compressible than the atom of chlorine.

Sodium Nitrate. This substance has the same crystal symmetry as calcite, so that the compressibility must be measured in two independent directions, parallel and perpendicular to the axis of trigonal symmetry. The original material was Kahlbaum's purest. It was formed into a single crystal block by my method of slow lowering from the furnace in the molten condition. It was melted in a funnel shaped container of pyrex glass; this has the disadvantage that it sticks on solidifying to the sides of the mold and the resultant block contains many cracks, but in spite of this it was possible to get from the block unfractured pieces large enough, the piece parallel to the trigonal axis being 0.97 cm. long, and that perpendicular to it 0.82 cm. Since sodium nitrate is not soluble in kerosene, the measurements were made in the lever apparatus for short specimens. The measurements on the specimen parallel to the trigonal axis were much more regular than on those perpendicular to it. At 30° the average departure of a single reading from a smooth curve for the perpendicular specimen was 0.9% of the maximum measured effect, and at 75° 0.7%. For the parallel specimen the corresponding figures were 0.1% and 0.4%.

The following are the results for the linear compressibilities. Perpendicular to the trigonal axis:

At 30° $-\Delta l/l_0 = 7.093 \times 10^{-7}p - 5.88 \times 10^{-12}p^2$,

At 75° $-\Delta l/l_0 = 7.643 \times 10^{-7}p - 4.41 \times 10^{-12}p^2$.

Parallel to the trigonal axis:

At 30° $-\Delta l/l_0 = 24.36 \times 10^{-7}p - 23.5 \times 10^{-12}p^2$,

At 75° $-\Delta l/l_0 = 23.36 \times 10^{-7}p - 21.4 \times 10^{-12}p^2$.

From these values of linear compressibility the following may be calculated for the cubic compressibility:

At 30° $-\Delta V/V_0 = 38.54 \times 10^{-7}p - 39.2 \times 10^{-12}p^2$,

At 75° $-\Delta V/V_0 = 38.64 \times 10^{-7}p - 35.8 \times 10^{-12}p^2$.

The compressibility at low pressures at 0° has been found by Madelung und Fuchs[8] to be 37.7×10^{-7}, agreeing fairly well with the initial value of the above formulas.

The compressibility of sodium nitrate has several interesting features. The compressibility in the parallel direction is more than three times as great as in the perpendicular direction. In the perpendicular direction the temperature coefficient of compressibility is positive, as is normal, but the numerical value of the coefficient is much larger than normal. In the parallel direction, the temperature coefficient of compressibility is negative, which is abnormal. Calcite is also three times more compressible parallel to the trigonal axis than at right angles, but the absolute magnitudes are only one-third as large.

Rochelle Salt. This belongs to the orthorhombic system, so that observations are necessary in three mutually perpendicular directions. The rods were cut from a single large crystal, which I owe to the kindness of the General Electric Co. It was prepared by the method of slowly lowering the temperature of a saturated aqueous solution. This crystal was prepared at least five years before the measurements were made on it. During these years it has been wrapped in Japanese crepe paper in a tightly closed wooden box; the surface still retained the original glass-like perfection. This material does not dissolve in kerosene, so that measurements were made in the lever apparatus for short specimens. The pressure range was 12000 kg as usual, but it was possible to measure only at 30°, because Rochelle salts loses its water of crystallization at about 37°, making the usual measurement at 75° impossible.

The designation of the directions used in the following is that usual with crystallographers, for example as that used by Mandel[10] in his recent paper on the elastic constants. The *a* and *b* directions are at right angles to each other, and lie in the large basal face, *b* bisecting the angle of approximately 80°, and *c* is perpendicular to both *a* and *b*. The lengths of the specimens measured were as follows: *a*, .73 cm; *b*, .91 cm; and *c*, 1.17 cm. The measurements in all three directions went rather smoothly; the average departure of a single reading from a smooth curve in terms of the maximum effect was 0.9% for the *a* direction, 0.09% for the *b* direction, and 0.29% for the *c* direction. In each direction the departures from a second degree curve were very large, so that the results must be given in a Table, which follows.

TABLE II.

Compressibility of Rochelle Salt at 30°.

Pressure kg/cm²	$-\Delta l/l_0$			$-\Delta V/V_0$
	a	*b*	*c*	
2000	.00245	.00506	.00333	.01080
4000	.00460	.00969	.00600	.02016
6000	.00651	.01414	.00847	.02885
8000	.00843	.01833	.01085	.03716
10000	.01029	.02217	.01320	.04501
12000	.01209	.02586	.01531	.05237

The cubic compressibility of Rochelle salts has not been previously measured, but all of the elastic moduli have been measured by Mandel, from which the linear compressibilities can at once be calculated. Mandel's[9] values for the moduli in Abs. C. G. S. units are:

$s_{11} = 46.0 \times 10^{-10}$,
$s_{22} = 31.4 \times 10^{-10}$,
$s_{33} = 27.6 \times 10^{-10}$,
$s_{44} = 59.7 \times 10^{-10}$,
$s_{55} = 300.4 \times 10^{-10}$,
$s_{66} = 78.7 \times 10^{-10}$,

$s_{23} = 16.5 \times 10^{-10}$,
$s_{31} = -21.4 \times 10^{-10}$,
$s_{12} = -7.8 \times 10^{-10}$.

From these the linear compressibilities in kg units may be calculated to be:

Linear compressibility in a direction $(= s_{11} + s_{12} + s_{13}) = 16.8 \times 10^{-7}$,

Linear compressibility in b direction $(= s_{12} + s_{22} + s_{23}) = 40.1 \times 10^{-7}$,

Linear compressibility in c direction $(= s_{13} + s_{23} + s_{33}) = 22.7 \times 10^{-7}$.

By drawing smooth curves through the points given in the table and taking the tangent at the origin, the corresponding initial compressibilities given by my data are: 13.3, 27.1, and 19.5×10^{-7}. These are all considerably lower than the values of Mandel, and the difference is much too great to be explained by mere errors of observation. The difference must be ascribed to difference in the original material; it is well known that the electrical properties of Rochelle salt crystals may be very greatly altered by various processes of seasoning or dessication, and there is no reason not to expect corresponding variability in the elastic properties. The most natural explanation of the difference is difference of water content. It will be seen that the ratio of my compressibilities in different directions is not the same as that of Mandel; this means that different degrees of dessication affect the properties differently in different directions.

Ammonium Tartrate. The C. P. material of commerce occurs in large enough single crystals so that suitable pieces were found by selection. This material is monoclinic, so that, strictly, linear compressibility measurements are necessary in four directions to completely fix the behavior under pressure. However, the a axis, using the usual designation of the axes as given, for example, in Groth, is so nearly at right angles to b and c that the measurement in a fourth direction, exactly perpendicular to b and c, was dispensed with.

This material is not soluble in kerosene, so that the compressibility was measured in the lever piezometer for short specimens. The lengths of the specimens were as follows: a, 0.48 cm; b, 0.87 cm; and c, 1.00 cm. Readings were made to 12000 kg at both 30° and 75°. The departure of a single reading from a smooth curve in terms of the maximum effect was: a direction, 1.2% at 30° and 1.4% at 75°; b direction, 0.3% at 30° and 0.2% at 75°; c direction, 0.16% at 30° and 0.34% at 75°.

Within the limits of error the relation between change of length and pressure can be represented by a second degree curve in the pressure. The results follow:

a direction

At 30° $-\Delta l/l_0 = 8.47 \times 10^{-7}p - 16.8 \times 10^{-12}p^2,$

At 75° $-\Delta l/l_0 = 8.75 \times 10^{-7}p - 19.3 \times 10^{-12}p^2.$

b direction

At 30° $-\Delta l/l_0 = 13.71 \times 10^{-7}p - 9.3 \times 10^{-12}p^2,$

At 75° $-\Delta l/l_0 = 14.51 \times 10^{-7}p - 11.8 \times 10^{-12}p^2.$

c direction

At 30° $-\Delta l/l_0 = 26.85 \times 10^{-7}p - 46.1 \times 10^{-12}p^2,$

At 75° $-\Delta l/l_0 = 27.48 \times 10^{-7}p - 48.2 \times 10^{-12}p^2.$

Approximate volume compressibility:

At 30° $-\Delta V/V_0 = 49.03 \times 10^{-7}p - 79.3 \times 10^{-12}p^2,$

At 75° $-\Delta V/V_0 = 50.84 \times 10^{-7}p - 87.0 \times 10^{-12}p^2.$

Again we find a compressibility in one direction about three times as great as in another. The behavior of the compressibility with temperature and the second degree terms offer no unusual features.

Tartaric Acid. This was prepared by slow evaporation in the constant temperature room from aqueous solution of commercial C. P. material. The crystal is monoclinic; the *a* axis is inclined at 80° to the plane of *b* and *c*, and as in the case of ammonium tartrate the compressibility was determined only along the three crystallographic axes. The lengths of the specimens in the *a*, *b*, and *c* directions were respectively: 0.77, 0.62, and 0.67 cm. This material is also not soluble in kerosene, and the measurements were made in the lever apparatus for short specimens. Measurements were made to 12000 kg at 30° and 75°. In the *c* direction an unusual seasoning effect was found, the points obtained with increasing pressure being irregular and lying far off the descending curve, which by every appearance was the correct curve. Discarding the ascending points of the *c* direction, the average departures of a single reading from a smooth curve at 30° and 75° were respectively: *a* direction, 0.5% and 0.9%; *b* direction, 0.1% and 0.02%; *c* direction, 0.5% and 0.13%.

The results can be reproduced by a second degree expression in the pressure, and are as follows:

a direction

At 30° $-\Delta l/l_0 = 8.19 \times 10^{-7}p - 11.7 \times 10^{-12}p^2,$

At 75° $-\Delta l/l_0 = 8.26 \times 10^{-7}p - 13.8 \times 10^{-12}p^2.$

b direction

At 30° $-\Delta l/l_0 = 50.78 \times 10^{-7}p - 110. \times 10^{-12}p^2,$

At 75° $-\Delta l/l_0 = 53.63 \times 10^{-7}p - 126. \times 10^{-12}p^2.$

c direction

At 30° $-\Delta l/l_0 = 10.89 \times 10^{-7}p - 16.0 \times 10^{-12}p^2,$

At 75° $-\Delta l/l_0 = 13.73 \times 10^{-7}p - 33.1 \times 10^{-12}p^2.$

Approximate volume compressibility, obtained by treating these three directions as if perpendicular:

At 30° $-\Delta V/V_0 = 69.86 \times 10^{-7}p - 148 \times 10^{-12}p^2,$

At 75° $-\Delta V/V_0 = 75.62 \times 10^{-7}p - 186 \times 10^{-12}p^2.$

The temperature coefficient of compressibility in the *b* and *c* directions has the normal sign, but is abnormally large. There is no simple connection between the compressibility of tartaric acid and of ammonium tartrate, the roles of the *b* and the *c* axes being reversed.

Diphenylamine. The origin of this was chemically pure material from Kahlbaum. It was made into large single crystals from the melt in a thermostat. This ordinarily crystallizes in thin plates, but by holding at the melting temperature for several days the plates were induced to grow to about 3.8 mm thickness, sufficient to give the compressibility perpendicular to the face of the plate, the *c* direction, by piling together two pieces. This material is monoclinic but again the three axes are nearly at right angles, and the linear compressibility was determined only in the direction of the axes. The designation of the axes is that of Groth, the *a* and *b* axes being in the flat face, at right angles, and the *c* axis perpendicular to both.

Diphenylamine is soluble in kerosene, so that it was necessary to use the piezometer for organic substances, submerging the crystal beneath mercury. Measurements were made to 12000 kg at 30°; the melting point is at about 54°, so that the customary measurements at 75° could not be made. In the *c* direction the points at 11000 and 12000 lay off the curve, there being evidently some sort of interference with the free motion of the slide wire. With the exception of these two points, the average deviation of a single reading from a smooth curve, in terms of the maximum effect, was 1.1% for the *a* direction, 1.2% for the *b* direction, and 0.4% for the *c* direction. The corrections were not as large a fraction of the total effect as is sometimes the case, being 8% in the *a* direction, 8% in the *b* direction, and 10% in the *c* direction. The lengths of the *a* and the *b* specimens were 0.8 cm.

The relation between change of dimensions and pressure is distinctly not of the second degree, so that the results are best exhibited in the following table:

TABLE III.

COMPRESSIBILITY OF DIPHENYLAMINE AT 30°.

Pressure kg/cm²	$-\Delta l/l_0$ *a*	 *b*	 *c*	$-\Delta V/V_0$
3000	.0147	.0145	.0164	.0463
6000	.0259	.0256	.0266	.0802
9000	.0358	.0353	.0332	.1079
12000	.0442	.0435	.0383	.1313

The compressibility is very much more nearly equal in the three directions than is usually the case for crystals. This means that the change of volume can be calculated with very little error from the linear changes. The volume compressibility is high for a solid, and is almost exactly the same as for liquid glycerine, the least compressible organic liquid yet measured.

$(NH_3C_2H_5)_2SnCl_6$. This material I owe to the kindness of Dr. R. W. G. Wyckoff of the Rockefeller Institute for Medical Research. Particular interest attaches to it because it is one of the few organic substances which crystallize in the trigonal system, and because its X-ray structure has been completely worked out.[10] The substance crystallizes in the form of hexagonal plates; two plates were available of a thickness of 0.16 and 0.12 cm. Two determinations of compressibility are necessary, one parallel to the hexagonal face and one perpendicular to it. The parallel specimen had a length of 0.65 cm. The perpendicular measurements were made on pieces cut from the two plates, piled together. The measurements had to be made in the piezometer for organic substances, submerged under mercury, for the double reason that it is dissolved by kerosene and it is too soft mechanically to withstand the necessary compression in the lever apparatus. The specimens were prepared by shaving off the excess material with a razor blade. It was not possible in this way to make as perfect specimens as by grinding, and the results are much more irregular than usual, both because of the geometrical imperfection of the specimens and because of their small size.

No attempt was made to measure the compressibility at 75°. The accuracy was not great enough to give departures from linearity. With the parallel specimen the average departure of a single reading from a straight line was 5% of the maximum effect. With the perpendicular specimen, there was some sort of permanent change produced by the pressure, and the points with increasing and decreasing pressure lay on two different lines of approximately the same slope, the average departure of a single reading from one or the other of these lines being about 1.5%. The material is affected in some way by its contact with kerosene under pressure, its mechanical texture becoming more friable, and the appearance being almost as if it had been amalgamated, although retaining its original shape. The corrections were about 5% of the measured effect. The results follow:

30°, average to 12000 kg/cm^2,

$$-\Delta l/l_0 = 3.95 \times 10^{-6}p, \text{ parallel to hexagonal face,}$$

$$-\Delta l/l_0 = 5.75 \times 10^{-6}p, \text{ perpendicular to hexagonal face,}$$

$$-\Delta V/V_0 = 12.9 \times 10^{-6}p.$$

The volume compressibility is thus sensibly greater than that of diphenylamine, and is the largest yet measured in a crystalline solid. The difference of compressibility in the two directions is not as great as might be expected.

Bakelite. The new piezometer for organic substances was first checked as to its proper functioning by measuring with it the compressibility of bakelite. Although this is not a chemically well defined substance, it is used to some extent in the construction of instruments, and the results found are therefore tabulated as being of some practical interest. The material investigated was the clear light yellow material, in appearance like amber. The relation between pressure and change of length is not of the second degree. The following are the results, the change of volume being calculated on the assumption of equal compressibility in all directions. Meas-

TABLE IV.

COMPRESSIBILITY OF BAKELITE AT 30°.

Pressure kg/cm^2	$-\Delta l/l_0$	$-\Delta V/V_0$
4000	.0250	.073
8000	.0437	.125
12000	.0577	.163

urements were made only at 30°. The compressibility is seen to be high, getting up into the class of organic liquids.

Discussion and Summary.

The effect of pressure on the electrical resistance of four metallic elements is measured. The resistance decreases with rising pressure in all cases, as is normal, with the exception of an initial effect found in arsenic. The compressibility of four elements, seven inorganic single crystals, four organic crystals, and bakelite is measured. A new form of piezometer has been developed for those substances which dissolve in kerosene. Arsenic has a new polymorphic form at high pressures, the transition pressure at 30° being about 5500 kg/cm^2. The compressibility differences of single crystal arsenic in different directions are very large. The compressibility measurements make it probable that boron does not crystallize in the cubic system. The organic crystals in general do not show as large compressibility differences in different directions as inorganic crystals. The absolute compressibility of the organic solids is high, the volume decrease under 12000 kg/cm^2 being of the order of 15%.

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THE MINIMUM OF RESISTANCE AT HIGH PRESSURE.

By P. W. Bridgman.

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INTRODUCTION.

THE electrical resistance of most metals decreases with rising pressure, but there are about half a dozen whose resistance increases.[1] Two examples are known, *Cs* and *Ba,* in which the two types of behavior are combined in a single substance, that is, the resistance at first drops, passes through a minimum, and then rises again at higher pressures. In general, if the resistance is plotted against pressure, it will be found that whether resistance increases or decreases with pressure the curvature is always the same, namely convex toward the pressure axis. The possibility of such behavior as that of *Cs* and *Ba* with their minimum resistance is evidently consistent with the common direction of curvature of all the curves. It was therefore natural to ask whether the minimum of resistance would not be found to be characteristic of all metals if pressure could only be pushed high enough. It is natural to look for this effect first in rubidium, the next most compressible metal after caesium; in fact, an extrapolation of the experimental values beyond the pressure range of the previous experiments, which was 12,000 kg., indicated that such a minimum was not impossible within a realizable pressure range. This paper contains an account of the actual attaining of the suspected minimum of rubidium with a new apparatus capable of reaching about 20,000 kg., of very definite indications of such a minimum for potassium at a pressure of 23,500 kg., 3500 kg. beyond that actually reached, and of new measurements on sodium to 18,000 kg., which indicate by extrapolation a minimum near 28,000 kg. In addition, the previous measurements on bismuth are extended to 50% beyond the previous maximum with no change in the trends previously found.

Two new pieces of apparatus were made for the higher pressure range. They were so much like the conventional apparatus of all my high pressure work that no extended description is necessary. Ordinarily there are two pressure cylinders, an upper one in which pressure is produced by the motion of a plunger, and a lower cylinder, connected to the upper one with a heavy pipe, in which is placed the particular substance to be investigated. The connecting pipe and the consequent large volumes are a disadvantage of this type of apparatus when attempting very high pressures. The new apparatus was therefore made in a single piece, being essentially the conventional upper cylinder, made longer than usual so that there was room in the bottom part for the resistance specimen. It is practically the same sort of thing that I used many years ago in measuring the transitions of ice up to 21,000 kg.[2]

The cylinders were of chrome vanadium steel, heat treated and subjected to several seasoning applications of 25,000 to 30,000 kg. in the usual way. The first cylinder was used for all the measurements except those on sodium. It is probable that a flaw was developed in this cylinder by the seasoning process, because a number of times there were leaks for which no adequate explanation appeared. This sort of behavior is the usual preliminary to the ultimate development of a well defined crack. Such a crack did not appear during this work, however, and at the expense of considerable trouble and a number of repetitions, enough runs were obtained without leak to give the information desired.

The second cylinder, that used with sodium, was given a preliminary seasoning like the first, and then, because of press of other work, was laid aside for about six months before making the actual measurements. The maximum pressure reached during the measurements with this was 18,000 kg.; here the steel stretched so much that higher pressures could not be reached, and this in spite of the fact that the initial seasoning had been made to nearly 30,000 kg. That is, the internal stress distribution produced by the original heavy overstrain gradually decays with time, and the elastic limit sinks toward the original value. This is in line with my previous experience, but I was not prepared for so large an effect. It is evident that in order to reach the highest pressures the measurements must be made as soon as possible after the preliminary treatment, and only a short life can be expected for the apparatus. The data obtained for sodium with this cylinder up to 18,000 indicated that the expected minimum would be beyond the range possible with this grade of steel, so that it did not seem worth while to construct a new cylinder for the comparatively small increase of range that would have been possible.

In order to maintain temperature constant, the lower end of the hydraulic press as well as the cylinder itself had to be placed in the temperature bath.

A special three terminal insulating plug was made for this experiment, the depth of the mica washers being 50% greater than normal. The additional friction of the washers against the steel walls due to their additional depth provides an additional element of strength. The manganin gauge with which pressure was measured was wound from the same spool of wire as the standard gauge, and was calibrated by direct comparison with the standard. The resistance was only 25% of the standard, and for that reason the sensitiveness of the pressure readings was not so great as usual, but nevertheless the sensitivity was great enough to correspond to the accuracy of the calibration of the standard. It is to be remembered that the original calibration of the manganin by means of an absolute gauge covered a pressure range of only 13,000 kg.,[3] so that measurements beyond 13,000, which must be made by linear extrapolation, are not so certain as the measurements below 13,000. In view of the smallness of the coefficient of the manganin the uncertainty from this extrapolation is probably low. In any event, a small error in the gauge beyond 13,000 can only affect the pressure of the minimum and not the existence of the minimum itself, which was the point of chief interest in this investigation.

There follows now the detailed presentation of data.

DETAILED DATA.

Rubidium.—The same metal which had been used in previous measurements and which had been purified by slow fractional distillation,[4] was used again. It had been kept sealed in glass under nujol since the previous measurements. It was extruded to a diameter of about 1.6 mm. and bent into a hairpin 5 or 6 cm. on a side. The potential and current terminals were, as before, fine wires of silver pierced through the rubidium wire and pinched into contact with it. The hairpin was mounted in a glass tube filled with nujol, the terminals were carried over the mouth of the tube and bent back over the outside, and the whole thing attached to a holder carried by the three terminal plug and thrust as a single assembly into the high pressure cylinder. Immediately before assembling in the cylinder the nujol was flushed out and completely replaced with petroleum ether; this was necessary because the viscosity and freezing point of the transmitting liquid must both be low in order to transmit high pressure.

In addition to a number of unsuccessful runs, three runs were made which yielded satisfactory measurements. The first, at 30°, was to a maximum pressure of 17,800 kg., it being impossible to get higher because of leak. This run disclosed a remarkable flattening of the curve of resistance against pressure, so that it seemed highly probable that a maximum was near. The second run reached a maximum of 19,350 kg., where there was a slow leak. This run disclosed a minimum with both increasing and decreasing pressure, the best value for the location of the minimum being 17,900 kg. The discrepancy between readings with increasing and decreasing pressure on this run was so large, however, amounting to about 2.3% of the resistance at the minimum, that improvement seemed desirable. The discrepancy between ascending and descending readings is doubtless due in most part to the chemical action between the transmitting medium and the rubidium; a similar effect has been found in all my previous measurements of the resistance of the alkali metals when the metal has been used in the form of a bare wire. Another explanation of the discrepancy which might seem plausible is hysteresis due to internal strains, but the direction of the hysteresis is in the wrong direction to admit this explanation. In the effort to diminish the discrepancy as far as possible, the petroleum ether with which pressure was transmitted in the third set-up was made as chemically inert as possible by standing in contact with metallic sodium for a number of days before the run. The maximum pressure reached on the third run was 19,800 kg., where there was a slow leak. Again a minimum was found with increasing and decreasing pressure. The discrepancy between the ascending and descending points was now of the order of 1% of the resistance at the minimum; in general the points were much more regular than those of the second run, and were satisfactory enough.

The experimental points of the third run are shown in Figure 1. The points obtained with increasing pressure are doubtless to be preferred to the descending points, since the time during which chemical action may occur is less for these points. The relative resistances between 12,000 and 20,000 kg. at convenient pressure intervals, obtained from the increasing readings, are shown in Table I. A check on these readings is afforded by the readings previously obtained up to 12,000. These previous readings were made at 0° and 35°; by linear interpolation the relative resistance at 30° and

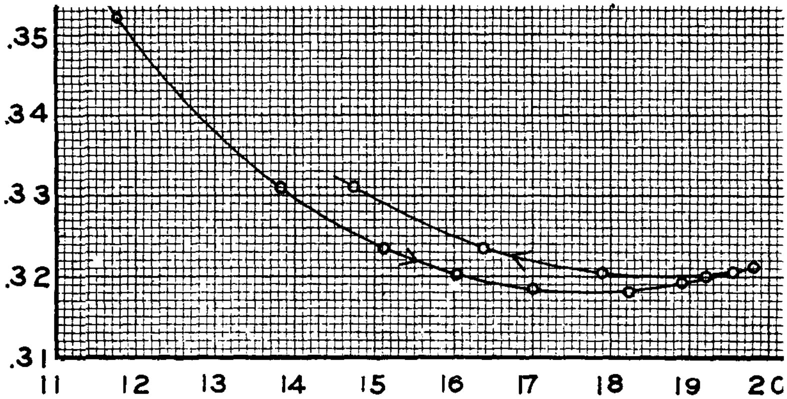

FIGURE 1. The measured relative resistance at 30° of rubidium against pressure in thousands of kg./cm.^{2} as abscissas.

12,000 kg. is found to be 0.340, against 0.349 found now, a difference of 2.6%. The previous value is probably to be preferred, the difference being in the direction to indicate greater chemical action in the present experiment.

TABLE I.

RELATIVE RESISTANCE OF RUBIDIUM AT 30°, FROM THE SMOOTH CURVE THROUGH THE POINTS OBTAINED WTIH INCREASING PRESSURE OF THE PRESENT EXPERIMENT.

Pressure kg./cm.^{2}	R/R_0
12,000	.3490
14,000	.3295
16,000	.3202
17,000	.3184
18,000	.3180
19,000	.3194
20,000	.3220

In Table II is shown the relative resistance at 30° at 1,000 kg. intervals up to 20,000 kg., to three significant figures. Up to 12,000 this table was constructed by linear interpolation between the previous values for 0° and 35°. Above 12,000, the values were obtained by applying a correction of 2.6% to the values of Table I, making a slight readjustment in the neighborhood of 12,000 to secure smooth first differences.

TABLE II.

MOST PROBABLE RELATIVE RESISTANCES OF RUBIDIUM AT 30°, OBTAINED BY COMBINING PREVIOUS AND PRESENT EXPERIMENTS.

Pressure kg./cm.^{2}	R/R_0
0	1.000
1,000	.819
2,000	.702
3,000	.619
4,000	.555
5,000	.504
6,000	.463
7,000	.430
8,000	.403
9,000	.381
10,000	.364
11,000	.350
12,000	.338
13,000	.328
14,000	.321
15,000	.316
16,000	.312
17,000	.310
18,000	.310
19,000	.311
20,000	.314

The most important result is that at 30° the resistance of rubidium passes through a minimum at 17,000 kg., where the resistance is 0.310 of its value at atmospheric pressure at the same temperature. This may be compared with the corresponding result for caesium, which at 0° has a minimum of 4,200 kg. of about 0.71 the initial resistance.

Potassium.—Although in view of the very large increase of the pressure of the minimum on passing from caesium to rubidium it appeared highly improbable that the pressure of the minimum of potassium, granting that it exists, could actually be reached with this apparatus, nevertheless the additional information to be obtained by extending the pressure range by 60% might be expected to give valuable information as to the probable existence and location of such a minimum.

The experimental set-up was practically the same as for rubidium.

The material was from the same original batch as that on which my previous determinations of the effect of pressure on melting point, resistance, and compressibility were made;[5] it has been kept in the meantime sealed in glass under nujol. The readings, which are shown in Figure 2, were very regular, there being very little difference between the ascending and descending branches. It is to be expected that any discrepancy between ascending and descending points would be much less in this case than for rubidium, both because potassium is less active chemically than rubidium, and because it is not so soft mechanically.

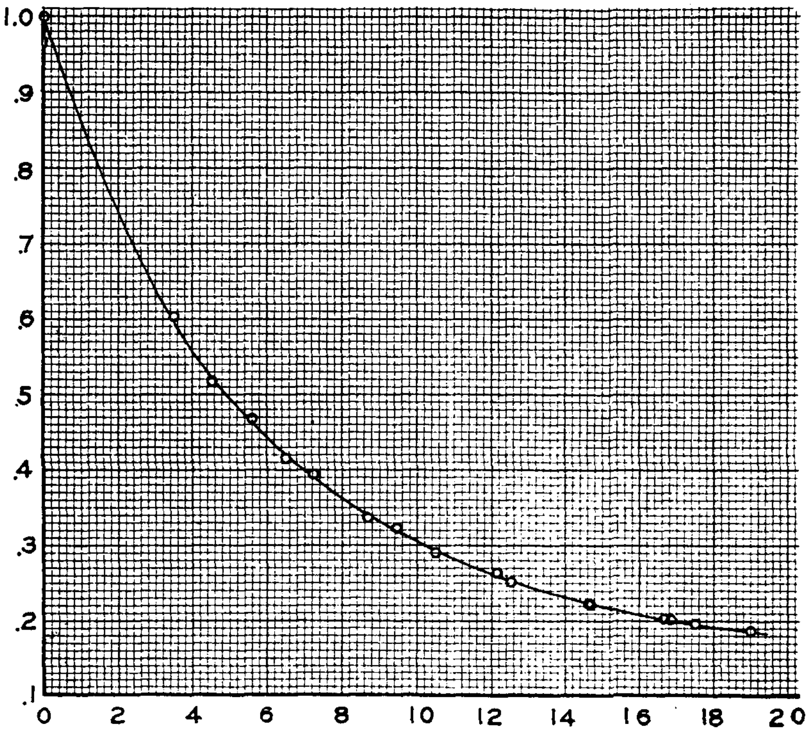

FIGURE 2. The measured relative resistance at 30° of potassium against pressure in thousands of kg./cm.^{2} as abscissas.

A fairly good check on the new results can be obtained by comparing with the previous measurements on potassium to 12,000 at 0°.

The present value for the relative resistance at 12,000 is 0.261, compared with 0.271 of the previous measurements. The difference, which is small, is in the right direction, and of a not unreasonable magnitude to be accounted for by the temperature difference. The previous measurements were made on potassium at only one temperature, so that a temperature interpolation could not be made such as was possible for rubidium.

The relative resistances in terms of the resistance at atmospheric pressure at 2000 kg. intervals up to 20,000 at 30° are shown in Table III.

TABLE III.

Pressure kg./cm.^{2}	Relative Resistances of Potassium at 30°
0	1.000
2,000	.734
4,000	.557
6,000	.443
8,000	.362
10,000	.305
12,000	.262
14,000	.231
16,000	.208
18,000	.192
20,000	.181

The minimum is seen to lie beyond 20,000. Direct extrapolation of the curve of resistance against pressure in order to find the minimum would not be accurate; this may be better done by plotting the first differences against pressure. In Fig. 3 the differences of relative resistance for 2000 kg. intervals are plotted against the mean pressure of the intervals. This curve is so nearly linear at the high pressure end that it can be extrapolated with little uncertainty. The curve is seen to cross the axis at about 23,500 kg., which may therefore be taken to be the pressure of the minimum. The minimum relative resistance calculated from the extrapolated first differences is 0.175. The pressure of the minimum is thus not so high as might have been anticipated from the relatively large increase in the pressure of the minimum on passing from caesium to rubidium.

Sodium.

The specimen was formed and treated in the same way as *Rb* and *K*. The material was from the same batch as that whose pressure

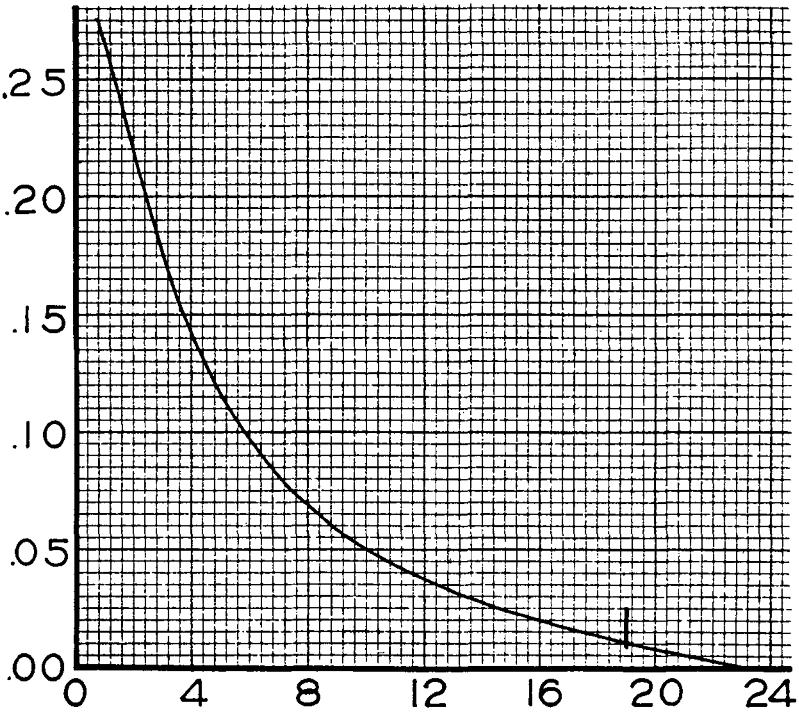

FIGURE 3. The first differences of relative resistance for 2000 kg. intervals of potassium plotted against pressure in thousands of kg.cm.^{2} as abscissas.

coefficient of resistance and melting curve under pressure were previously measured,[6] and which gave evidence of high purity by the sharpness of the freezing point. It has been kept since that time in a glass stoppered jar under kerosene. There has been some surface action with the kerosene, but the piece used was cut from the interior of a large block, and should be as pure as the original.

Measurements were made at 30° in the second cylinder; as already explained, the cylinder stretched so much beyond 18,000 kg. that readings could not be obtained at higher pressures. The measured relative resistances are plotted in Fig. 4. There is considerable difference between the ascending and descending readings at the lower pressures, which becomes much smaller beyond 10,000 kg. It is uncertain how much of this is due to chemical action and how much to mechanical distortion. If the mean of the two zero readings is taken as most probably correct, it will be found that the relative resistance at 12,000 kg. is .4210 against .4245 previously found. The difference is only 0.82%. It is probable that the previous values are to be preferred, since more attention was then paid to the low pressure behavior. Agreement between the two sets of data at

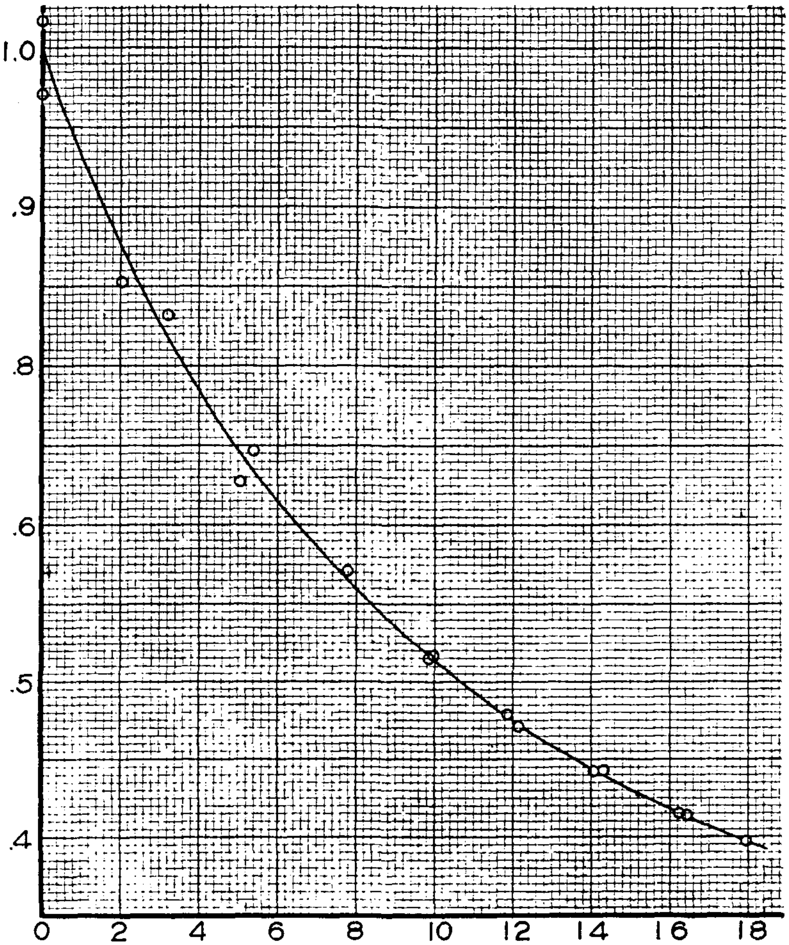

FIGURE 4. The measured relative resistance at 30° of sodium against pressure in thousands of kg./cm.^{2} as abscissas.

12,000 can be obtained by assuming that the proper zero of these measurements is not the mean of the two observed zeros, but about 0.3% higher. The smooth curve in Fig. 4 has been drawn in accordance with this adjustment.

The relative resistances at 1,000 kg. are shown in Table IV. The four significant figures given are justified by the data, and it is in fact necessary to retain this number of figures to obtain smooth first differences. Compared with the previous results at 12,000 the maximum difference is 3 in the third figure at 4,000 and 5,000, and the average difference 1.

TABLE IV.

Pressure kg./cm.^{2}	Relative Resistances of Sodium at 30°
0	1.0000
1,000	.9338
2,000	.8770
3,000	.8278
4,000	.7850
5,000	.7480
6,000	.7156
7,000	.6866
8,000	.6601
9,000	.6361
10,000	.6141
11,000	.5941
12,000	.5757
13,000	.5590
14,000	.5442
15,000	.5308
16,000	.5185
17,000	.5073
18,000	.4974

In order to estimate whether there is a minimum resistance, the differences for 1,000 kg. intervals are plotted against pressure in Fig. 5. There can be little doubt that the curve will cross the axis, so that it is highly probable that *Na* has a minimum as well as *Cs*, *Rb* and *K*. The dotted extension of the curve in Fig. 5 fits smoothly with the experimentally determined part, shown as a full line, and indicates a minimum near 28,000 kg., with a minimum relative resistance of 0.442.

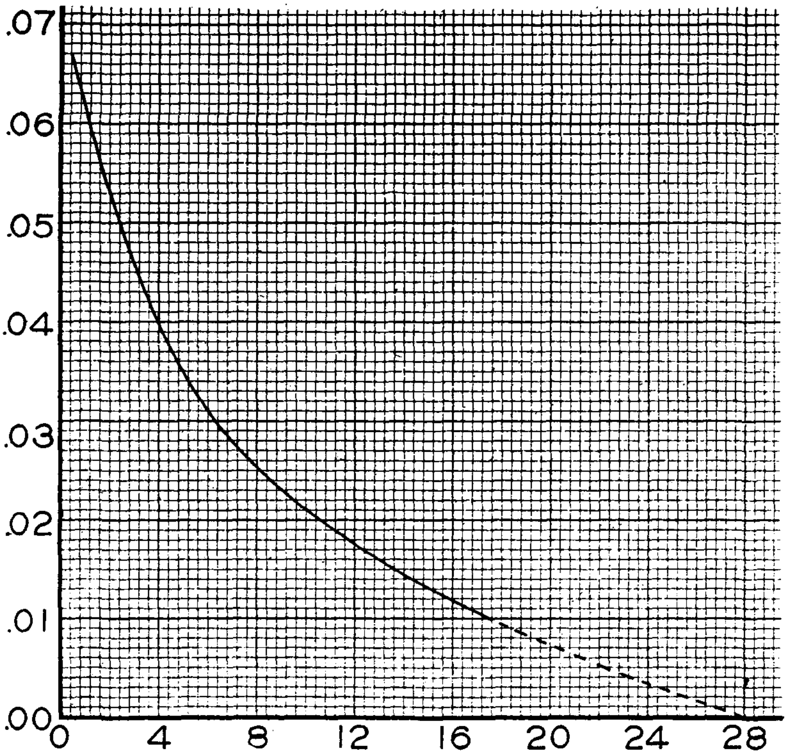

FIGURE 5. The first differences of relative resistance for 1000 kg. intervals of sodium plotted against pressure in thousands of kg./cm.^{2} as abscissas.

Bismuth.

My particular reason for trying bismuth to higher pressures than formerly was that because of the abnormal increase of volume of bismuth on freezing it is to be expected that at sufficiently high pressures a new high pressure modification may exist, analogous to the high pressure forms of ice. Any such polymorphic transition should disclose itself by a discontinuity in the resistance.

The material was a single crystal rod of bismuth, with cleavage plane parallel to the length, from the same set of rods whose thermoelectric properties and resistance under pressure have been previously measured.[7] With this rod a single run was made to a maximum pressure of 18,400 kg. at 30°. The points lay perfectly smoothly, with no perceptible difference between the ascending and descending points, and no indication whatever of any sort of discontinuity. The transition, if it exists, must therefore occur at pressure beyond 18,400, or else the transition was suppressed by internal viscosity.

Previously measurements have been made to 12,000 on a crystal with cleavage at 4° to the length, and the results represented by a second degree expression in the pressure. We have to ask in the first place whether the new results agree with the former ones over the common pressure range, and secondly whether the second degree expression may be used to extrapolate beyond 12,000. The formula gives for the relative resistance at 12,000 1.168, against 1.162 found now, and at 18,000 1.284, against 1.273 found now. The differences are thus small, and are in the direction to be accounted for by the slight difference in orientation. The present values may therefore be considered checked, and the use of the previous formulas by extrapolation up to 18,000, and presumably materially higher, is justified.

It is to be remarked that we have here also presumptive evidence of the legitimateness of extrapolating the manganin gauge calibration beyond 13,000. One method of checking such an extrapolation would be to find whether the same pressure is given by extrapolating with the formulas for two different metals; this is essentially what has been done here.

Discussion.

The chief conclusion to be drawn from the results of this paper is that it is almost certain that ultimately, at sufficiently high pressures, the resistance of all the alkali metals increases under pressure. This increase has actually been realized for *Cs* and *Rb*, and *Li* already at atmospheric pressure increases in resistance; the extrapolation for *K* and *Na* is not a large one, and it seems practically certain that they also must ultimately increase in resistance.

It is natural to look for regularities in the minimum data on passing from metal to metal in the alkali series. It is evident in the first place that *Li* is entirely out of the sequence. This perhaps is not surprising in view of the very simple electronic structure of the atom of *Li*, compared with that of the others. Consider now the remaining four metals *Na*, *K*, *Rb*, and *Cs*; the essential data for them are collected in Table V. If the pressure of the minimum is plotted against atomic number, a fairly smooth curve will be obtained, the pressure of the minimum dropping at an accelerated rate in the direction of

Cs. If the relative resistance at the minimum is plotted against atomic number a parabolic curve will be found having a deep minimum at *K*. One is reminded of another respect in which *K* falls out of the sequence, namely in the very loose electronic structure of the atom and the surprisingly persistent compressibility at high pressures emphasized in a previous paper;[8] there does not, however, appear to be any very close correlation between these other effects and the behavior of resistance found here.

TABLE V.

Metal	Atomic Number	Pressure at minimum	$\frac{R(\text{min.})}{R(\text{atoms.})}$
Na	11	28,000*	.442*
K	19	23,500*	.175*
Rb	37	17,800	.310
Cs	55	4,200	.71

* Extrapolated.

The considerations of the introductory paragraph make it natural to suppose that the phenomena shown by the alkalies may be shown by all other metals at high enough pressures; we inquire at what pressures we might possibly find this effect. The alkali earth series is the most natural place to look next. Here barium does have the effect,[9] the pressure of the minimum being about 8600 kg. at 30°, and strontium and calcium[10] have a positive pressure coefficient already at atmospheric pressure like lithium. Beryllium,[11] however, the analog of lithium, has a normal negative coefficient, and magnesium[12] the analog of sodium, also has a negative coefficient. The resistance of *Be* and *Mg*, when plotted against pressure, shows curvature in a direction consistent with a minimum at higher pressures, as do all other metals, and the pressure of the minimum indicated by extrapolation of the second degree formula valid up to 12000 kg. is 46,000 kg. for *Be* and 49,000 for *Mg*. But a second degree formula almost certainly gives by extrapolation too low a pressure for the minimum, as shown by Figures 3 and 5, which would be straight lines if a second degree formula were valid. It is therefore evident that the possible minimum of *Be* or *Mg* is at a pressure so high that it is hopeless to try to reach it with present means, or even to get close enough to allow a secure extrapolation. Searching the rest of the measured elements, one would expect to find the effect most easily with the most compressible metals. Of these, thallium[13] gives by second degree extrapolation a pressure of 46,000 kg. and indium[14] 37,000, which again is certainly too low in view of the detectible departures from the second degree relation below 12,000. It would appear therefore that the only chance of finding the effect in the pressure range at present attainable is with some metal not yet investigated. The largest gap in the investigated metals is in the rare earths: here only a few have been measured, but they are not encouraging. Perhaps the most promising candidates are scandium and yttrium, but these have not yet been produced in sufficiently large quantities in the metalic condition.

The fact that bismuth and antimony have positive pressure coefficients of resistance in the ordinary range requires brief comment. In spite of the fact that the curvature of the plot of resistance against pressure is the same as that of the alkali metals and earths, it is not unlikely that the mechanism of the positive pressure coefficient is different in the two cases. In *Bi* and *Sb* the mechanism is probably special, connected in some way with the crystal structure, as shown by the fact that the coefficient of liquid *Bi* is negative.[15] The positive coefficient of the alkali metals and earths is probably more intimately connected with the structure of the atom, as shown by the fact that the coefficient of liquid as well as solid *Li*[16] is positive. It was shown in a previous paper[17] that it is highly probable that the coefficient of liquid *Cs* will also be positive at pressures high enough, and by analogy, one would expect similar behavior for the other alkali metals.

In speculations as to possible behavior at very high pressures, a significant feature of the behavior of *Cs* should be kept in mind. If the "instantaneous" pressure coefficient $\frac{1}{R}\left(\frac{\partial R}{\partial p}\right)_t$ of *Cs* is plotted against pressure, a curve will be obtained which crosses the axis at 4200 kg., the pressure of the minimum, and which in the low pressure range is rather strongly concave upward, so that a wide extrapolation might be taken to indicate a second crossing of the axis, with a maximum, which would mean that at pressures still higher the pressure coefficient of resistance would again become negative. But this extrapolation is not valid because of a reversal of the direction of curvature of $\frac{1}{R}\left(\frac{\partial R}{\partial p}\right)_t$, that is, a reversal of the third pressure derivative, above 8,000, so that above 8,000 kg. the pressure coefficient becomes increasingly positive, and there is no indicated possibility of a return to normal behavior at excessively high pressures. This has application to the other alkali metals; their third derivatives are such as not to make impossible a second reversal at exceedingly high pressures, but judging by the analogy of *Cs*, this initial possibility will be eliminated at high pressures, and there is no reason to think that the resistance of all these metals will not continue to increase at an ever accelerated pace at pressures far beyond the present experimental range.

The theoretical significance of the reversal of the pressure coefficient at high pressures is at present obscure; there does not seem to be any suggestion of such a phenomenon in the present wave-mechanics pictures of the mechanism of resistance. This must nevertheless be important not only for theories of resistance, but for theories of the structure of the atom, since we have here definite evidence of a reversal in ordinary atomic properties produced by forces which are not high in comparison with the forces between different electrons in the same atom. It may well be that there is here a possibility of obtaining by direct experiment some inkling of atomic behavior under certain stellar conditions.

I am much indebted to Mr. W. A. Zisman for making the measurements of this paper, and to the Milton Fund of Harvard University for financial assistance.

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THE REFLECTING POWER OF SOME SUBSTANCES IN THE EXTREME ULTRA-VIOLET.

By Paul R. Gleason.

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(Communicated by Theodore Lyman.)

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INTRODUCTION.

IN an earlier paper, the author[1] has presented the results of his work on the reflecting power of a number of substances to light of very short wave-lengths. It is intended here to add the results on three more mirrors and to describe in more detail the apparatus and methods used.

A total of twenty-five mirrors of seventeen different materials have been investigated. The light employed varied in wave-length from 585 Å to 1800 Å.

Previous Work.—Heretofore results on the reflecting power in this region of wave-lengths have been obtained either by qualitatively comparing the reflection of one substance with that of some standard mirror, or without resolving the light and taking advantage of the full intensity of the source over a wide range of wave-lengths, to get average numerical results.

Gardner[2] obtained qualitative results on nine metals for wave-lengths between 1700 Å and 1025 Å. He illuminated the slit of a vacuum spectrograph by light reflected at 45° from both speculum and the mirror under investigation. The spectrum produced was double; i. e. the light from each mirror produced in closely adjacent positions its respective spectrum. Since the two mirrors were simultaneously illuminated, any fluctuation in intensity of the source did not affect the relative intensities of the reflected spectra. Thus for each wave-length present the comparison with speculum could be made and was carried out for silicon, platinum, stellite, copper, nickel, gold, steel, silver, and aluminum. Numerical results were impossible because of the photometric characteristics of the Schumann plate. Absolute values necessarily would depend upon the mirror used as standard and the numerical value of its reflecting power at the various wave-lengths.

Pfund[3] studied speculum, silver, gold, platinum, quartz and glass. Numerical results were obtainable through the use of a thermopile. His source was a discharge in hydrogen so excited as to give principally the atomic spectrum. Its total radiation was first reflected by a concave glass mirror, and then by the mirror under investigation. He verified the fact that there was no radiation present of wave-length between 1300 Å and about 3000 Å by observing that a glass screen in the light beam reduced the response of the thermopile by the same amount as a fluorite screen. He thus could correct all readings for light of wave-length longer than 1300 Å by interposing the glass screen. Numerical values were obtained by first evaluating the reflecting power of glass and then substituting the other mirrors. The data obtained were for the wave-lengths between 912 Å and 1216 Å, principally the Lyman series. Undoubtedly the 1216 Å line predominated, although an appreciable effect from the 1026 Å line would be expected.

Pfund[4] has used another method by which he was able to trace the variation of the reflecting power with wave-length. Working photographically, he compared the spectrum obtained in the usual way with one obtained from light produced in a second branch of the same discharge tube which shone at 45° on the mirror under examination and thence to the slit of the same spectrograph. These results have not been numerical, but have served to discover maxima in the reflecting power of certain crystalline substances at wave-lengths just longer than the absorption band wave-length demanded by dispersion formulae.

Lewis and Hardy[5] did not resolve their light but used photoelectric cells whose targets had a long wave-length limit of photoelectric action near 1900 Å. This eliminated the necessity of screens, in that light affecting the cells was of wave-length long enough to go through quartz but not longer than the photoelectric limit of the target. Since they used a quartz mercury arc as source, their results refer principally to the 1849 Å mercury arc line.

Hulburt[6] performed some very important experiments on the reflecting power of metals. His work did not, however, extend into the region of primary interest here, as he worked in the near ultra-violet between 3800 Å and 1850 Å. He used a concave grating to analyze the light, and a photoelectric cell to measure intensities. Numerical values of the reflecting power were possible because the cell could be placed to receive not only the spectral lines formed in their usual positions, but also the same lines after reflection at 18° from the mirror under investigation. This was accomplished by turning the entire cell assembly through an angle of 144° and simultaneously bringing the mirror into position. Hulburt measured the reflecting power of twenty-eight metals by this method.

II. APPARATUS.

Optical Arrangements.—The general optical arrangements of Hulburt's were adapted to a vacuum spectrograph for the measurement of the reflecting power at the shorter wave-lengths. In a schematic way, Fig. 1 shows the optical features of the apparatus.

The light from a direct current discharge passed through the slit *S* to the grating *G* where it was reflected and analyzed, forming the spectrum on the circle through the slit and the surface of the grating. Certain of the first order lines, as *a* and *b*, fell on the photographic plate at *P*. If a mirror at *M* was interposed at 45° to the light beam, and the plate turned through 90° about the point *O* in the surface of the mirror, then the spectral lines *a* and *b* fell at a' and b' upon the plate in the new position P' without change of focus.

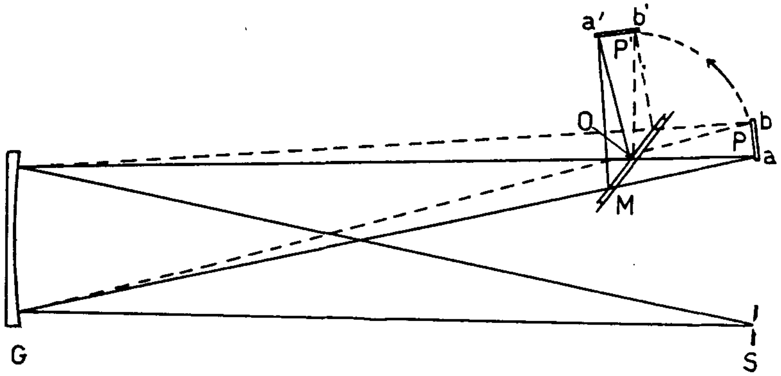

FIG. 1.

Vacuum spectroscope.—The details of the construction of the external vacuum chamber were roughly those described by Prof. Lyman.[7] However, the main drawn brass tube was closed at both ends by chambers cast in bronze. At one end the bronze chamber housed the grating and its mounting and was closed by a brass plate. At the other end the chamber contained the plateholder and mirrors. This one was closed with a hat-shaped cover carrying the four vacuum-tight tapers for external controls.

Grating and grating mounting.—The grating was of 50 cm. radius so that a short light path with small absorption in the spectrograph could be had. It was ruled on speculum metal at Johns Hopkins with 15,000 lines to the inch. The effective ruled surface was 4.5 cm. high by 8 cm. wide. This grating was carried on a carefully constructed mounting. In addition to the eight adjusting screws to provide usual adjustments, a divided circle coupled to a micrometer head enabled the operator to determine the position of the grating to better than a minute of angle. This was expedient because the narrow plate used could record but a 450 Å width of spectrum. Thus the grating had to be accurately turned to give known wavelength regions on the plate. Not only could these settings be made precisely and read through a window in the cover plate, but they could be made without disturbing the vacuum by turning a vacuum-tight taper mounted on the cover plate.

Plateholder and mirror assembly.—A screw mechanism to raise and lower the plateholder and thus to provide for as many as fifteen exposures on a single plate was an important feature of the spectrograph. Similarly, the mounting M for the mirrors was raised and lowered by a screw so as to accurately place either of three mirrors in the optical path or to remove them altogether. The motion of the plateholder from position P to position P' was simply taken care of by mounting it on a small bearing above M whose axis was vertical and passed through O. In addition to these three adjustments, a fourth was essential for focusing the plate. In fact, each angular position of the grating required a different position of the plate for focus. This was provided by the motion of the entire plateholder assembly along the axis of the instrument. A divided circle visible through a window indicated the position in regard to focus.

Each of these adjustments was made possible from the outside of the vacuum chamber by a vacuum-tight taper. This arrangement consisted of a steel inner taper carefully lapped into fit with a brass outer taper. The joint was made vacuum tight with stop cock grease.

Slits.—The slit ordinarily used was of the type described by Prof. Lyman.[8] Another design was necessary for the latter part of the work and will be described later (Fig. 4). On the average the slit was adjusted to a width of 0.04 mm. and a height of 0.20 mm.

Discharge tube source.—The source of light used was the direct current discharge in gases. The internal capillary tube exactly as used by Prof. Lyman[9] and constructed of quartz was employed during a large part of this work. A satisfactory substitute was constructed of pyrex as shown in Fig. 2. The opening S was cemented onto the slit of the spectrograph with the end of the internal capillary to within about 2 cm. of the slit. The inlet G served to admit the gas and to continuously replenish the supply.

The electrodes E_1 and E_2 were spirals wound from tungsten wire. The tungsten lead-ins were protected from the discharge by the quartz sleeves Q. Thence they passed through the inverted pyrex seal I to the lead tips L. These lead-in assemblies were demountable, being sealed into side tubes with De Khotinsky cement.

The currents possible with a pyrex tube were about as high as with the quartz tube of the former design. The usual condition of operation was at 900 volts and a gas pressure which permitted 50 m.a. current to pass. This current has been pushed to 60 m.a. with safety even for a period of five continuous hours of service. A small electric fan was required to protect the seals from overheating.

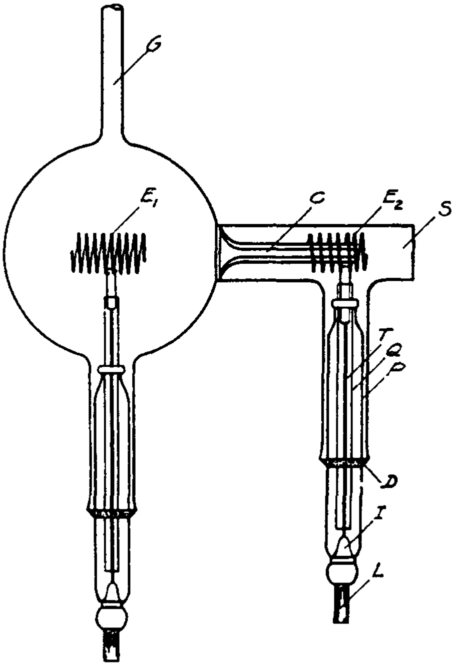

FIG. 2.

It is well known that the direct current discharge can not be started in a tube unless either the pressure is increased beyond operating conditions or the initial voltage increased. Neither method is desirable where great constancy is sought in the running conditions of the tube. The difficulty was solved by the use of a third electrode E_3 placed anywhere in the bulb with E_1 but insulated from it. Then to start the discharge, the operating direct voltage was supplied across E_1E_2 while across E_2E_3 the voltage from a high tension transformer was applied. The latter easily excited a discharge which the direct voltage could maintain.

The Capillary Valve.—Since there was constant leakage of gas from the discharge tube into the spectrograph through the slit, there had to be replenishment through *G*. Furthermore to insure a constant intensity of light it was fundamentally necessary to regulate accurately the flow of gas into the tube. The all-metal capillary valve shown in Fig. 3 accomplished this purpose. It consisted essentially of an inner taper T_1 of steel carefully fitted to and lapped into contact with the outer brass taper T_2. The inner taper was then fastened to the end of a vacuum tight screw and moved vertically with respect to T_2, thus varying the leak over wide limits. The vacuum screw was cut in brass at a half millimeter pitch. Care was taken in the cutting of the thread, both for the screw and nut, so that they fitted each other closely over the entire contour of the thread. With a four centimeter nut and a little stop cock grease worked into the thread, the valve was tight.

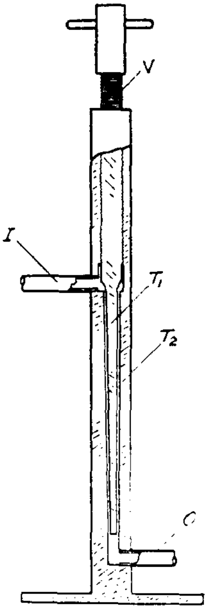

FIG. 3.

Sectored disk assembly.

To provide means for changing by known amounts the intensity of the light passing through the slit, the attachment shown in vertical section in Fig. 4 was used. This could be substituted for the slit first used without changing the focus of the instrument as a whole.

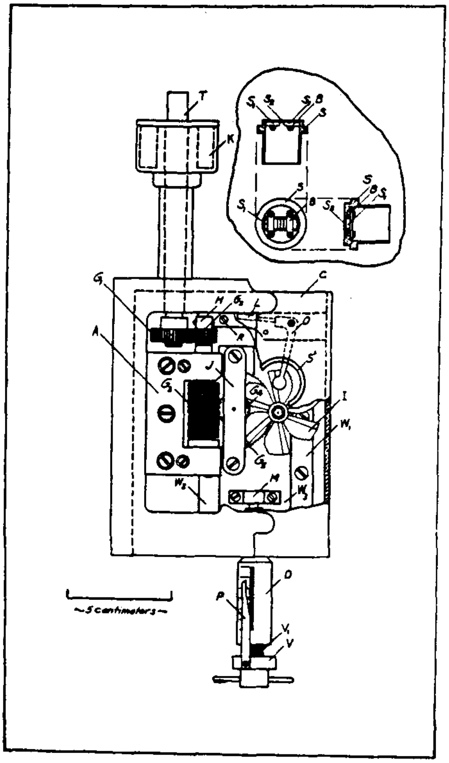
T
K
S_1
S_2
S_3
B
S
S
B
S_1
S_1
S
B
S_2
C
G_1
H
G_2
L
O
A
R
J
S'
G_3
G_4
I
W_1
G_5
W_2
M
W_3
~5 centimeters~
O
P
V_1
V

FIG. 4.

The reduction in intensity was accomplished by the rotation, just behind the slit, of the variable aperture sectored disk *I*. The actual disk had fifteen apertures for cutting the intensity to values from 50% to 2.5% of the incident light. It was desirable to produce sixty flashes of light per second which required that the disk revolve ten times each second.

The disk was mounted on the end of a small shaft on which was placed a 20 tooth spur gear, which meshed with the 100 tooth spur gear G_5. G_5 was on the same shaft wth G_4, a spiral gear meshing with the spiral gear G_3. In turn, G_3 was on the same shaft H with G_2 a spur gear meshing with G_1 and having a 1:2 ratio to it. G_1 was mounted on the end of a vacuum-tight taper T, which was belted through a gear reduction to a motor so that T would turn once a second. The taper T held the vacuum over many continuous hours of turning. Stop cock grease rich in vaseline served both as lubricant and vacuum seal.

Other mechanism was necessary to permit the vertical motion of the disk so as to bring desired apertures opposite the slit. For this I, G_4, G_5 and J which carried the shaft of these latter gears were all mounted on the plate W_3. This plate moved vertically in the fixed guiding ways W_1 and W_2. This motion was actuated by the vacuum screw V_1 turning in its nut D. In fact, the tip of V_1 pushed directly against M which was rigidly attached to W_3. Obviously the spiral gears G_3 and G_4 remained in mesh for all settings of the disk. The precise position vertically was read off the scale on D by means of the pointer P.

A magnetic shutter for starting and stopping the exposures was fastened to the back plate of the case to this assembly with a single screw. The armature L easily moved the shutter arm O about the pivot. Contrary to the drawing, the circular tip was behind the disk.

Since the disk was not more than three millimeters from the slit, it is easy to see that the individual steps of one millimeter each on the disk were ample. The whole disk was thus four centimeters in diameter. The disk was cut on a precision milling machine whose accuracy even on this small scale must have been at least to 1%. Careful measurements of the disk showed this to be true.

This assembly occupying as it did the position formerly taken by the simple slit mounting, required a special type of slit as shown in the figure. In this case the slit assembly fitted into the recession S' and had its jaws at the same distance from the grating as the other type of slit. In the newer slit the jaws S_1 were adjusted to the proper opening S_2 and then clamped into position with the bar clamps B. This arrangement facilitated the setting of the jaws of the slit.

Pumps and vacuum conditions.—With suitable drying tubes inserted, the spectrograph was connected to a Cenco Hyvac pump.

This pump was able to exhaust the system in about twelve minutes to a point where the high tension transformer could not excite a visible discharge in the test discharge tube. In spite of the many moving and stationary joints the pressure increased to only about a centimeter of mercury after leaving the apparatus idle for a week.

Gases for source radiation.—Commercial nitrogen and commercial oxygen (Matheson) were stored in liter flasks connected to the apparatus. An electrolytic generator provided hydrogen. Helium, which had been carefully purified for spectrum work, was obtained in a gasometer from Prof. Lyman's supply. In each case the gas was dried over phosphorus pentoxide and passed through a U-tube in liquid air before entering the discharge tube.

High voltage generator.—The voltage necessary for the direct current discharge was generated by an Electric Specialty Co. motor-generator. The motor was a 550 volt, three phase induction motor and the generator compound wound (1500 v) so the resulting voltage was very constant. The voltage could be closely regulated by a sliding contact rheostat in series with the field rheostat.

Photographic plate.—The photographic plate ordinarily used was the Cramers Red label, lantern slide plate. These were cut to size, and sensitized to the extreme ultra-violet by dipping in a solution of 10 drops of Nujol[10] in 40 c.c. petroleum ether. After exposure the plate was washed in petroleum ether and developed in the usual way.

Photometer.—The thermocouple photometer[11] of the Students' Astronomical Observatory (Harvard) was used for the measurement of the plates through the courtesy of Prof. Stetson. To the instrument described in the reference has been added a slit suitable for working with spectral lines, and a moving stage with micrometer screw motion to facilitate the placing of the various spectral lines over the photometer slit.

III. Experimental Methods.

Preparation of Mirrors.—In order that data on the reflecting power be significant, they should refer to clean surfaces of the pure material which have been formed to optical flatness and highly polished. These conditions are difficult to meet. Possibly the simplest method with the metals is to resort to cathodic sputtering. By this method, providing the deposit is formed on a surface that is clean, flat and highly polished, the deposit itself is in general an excellent mirror.

A thin, transparent film must not be used as its reflecting power would probably be too low. On the other hand, a thick film is inclined to peel. Hence, the most useful sputtered mirror is one which is intermediate in thickness.

The sputtering apparatus employed was designed to eliminate as far as possible contaminating vapors from the wax and greases used in sealing. The distance from the cathode to the mirrors to be coated was about 5 cm. The anode was of aluminum and so shielded that the a.c. source used for the sputtering would not permit the depositing of the aluminum on the mirror. So many variables are involved in the process that the time required to sputter a mirror is not of much significance. However, the approximate time is indicated.

Optical glass which was taken from plano-flat spectacle lens blanks from the American Optical Co., was cut to the 1 cm. by 3 cm. size for the mirrors. These had to be thoroughly cleaned to insure a good sputtered surface.

The opacity (i. e. the percentage of light absorbed in transmission) for most of the sputtered mirrors was measured. This was done on the thermocouple photometer employed in the measuring of the photographic plates. The readings did not in every case check rough visual measurements, but any discrepancy could be explained by the fact that the light source in the photometer undoubtedly was rich in infra-red radiation.

Other mirrors were prepared by polishing a solid block of the material. The methods used are described below.

Aluminum.—Although aluminum does not sputter readily, it was possible to prepare a mirror of 94% opacity during the course of eight hours sputtering in a residual atmosphere of argon. This was the only mirror sputtered with a direct current discharge.

Beryllium.—A specimen of this metal procured from the Beryllium Corporation of America was used for the sputtering. The first day's efforts were in vain, but it was finally possible to get a 98.5% opaque film. Once started, the sputtering proceeded fairly rapidly in the presence of argon.

Brass.—A piece of brass was machined* to approximate flatness and then lapped to an excellent polish and optical flatness on a dry jasper lap which had been previously made accurately flat.

*Chromium.**—A piece of carbon tool steel was machined into approximate shape and after hardening was ground and lapped on a tin lap with fine emery and sperm oil. It was then polished with diamantine[†] and alcohol on a boxwood lap. Chromium was electrolytically deposited on this steel mirror. The chromium surface presented a rather milky appearance so was polished lightly with diamantine on boxwood.

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* I am indebted to Mr. David Mann for the polishing of this mirror.

*Cobalt.**—The cobalt mirror was prepared from a solid piece of the metal obtained through the courtesy of Prof. Hall. It was ground and then lapped on a tin lap with fine emery and finally polished with diamantine on boxwood.

Fluorite.—A piece of a fluorite window was used without retouching as a mirror. It was from Zell in Baden, and had been polished by Thomlinson in 1925. It is difficult to produce a good optical surface on fluorite and doubtless this one had been scarred in its use as a window. At any rate the surface had a large number of pits and scratches in it.

Glass.—The glass mirror used was simply one of the blanks described for use in sputtering. The American Optical Company reports that this glass has an index of refraction of 1.523 for some wave-length in the visible.

Gold.—The mirror of gold was sputtered in about four hours to an opaque film. The gold had a tendency to peel from the glass because of the thickness.

Nickel.—Nickel also sputtered easily to a 96.7% opacity in about five hours.

Platinum.—The platinum surfaces were prepared with about three hours sputtering to a 99% opacity. Three different sets of sputtered surfaces were prepared.

Quartz.—The crystalline quartz mirror was prepared by cutting a flat window of that substance obtained from Ph. Apffel Co. (New York). The orientation of the crystal axes with respect to the reflection surface is unknown. The fused quartz mirror was cut from a fused quartz window that had been freshly repolished by the Jones and Hewett Optical Company.

Silver.—Silver was deposited chemically to an opaque film on optical glass to form the silver mirror.

Silicon.—No solid piece of this material could be found which was free from pits, so a solid metal mirror was not prepared. Furthermore silicon proved to be the most difficult substance to sputter.

[†] A trade name for a material used by watchmakers for polishing steel parts, probably it is fused borax finely powdered.

One mirror of 45% opacity was finally produced in thirty hours of sputtering in the presence of argon. An attempt at a more opaque mirror failed to go beyond the 45% opacity in one hundred and ten hours of sputtering. In both cases it was proven that aluminum sputters much more readily than silicon, because thick films of aluminum formed in the sputtering apparatus near the aluminum electrode.

Speculum.—The specimens of speculum were furnished by Fecker (Pittsburg) in a highly polished condition. They tarnished, however, before they could be used. In earlier work this was removed by lightly rubbing the surface on which drop chalk was deposited from an alcoholic suspension. Later it was found that light buffing with a rouged chamois gave a good surface. In neither case was it possible to remove the tarnish without leaving a few light scratches.

A speculum blank furnished by Prof. R. W. Wood was used to sputter a speculum mirror on glass. A brilliant surface was produced. This mirror may have departed from the exact percentage composition of the speculum, but it had all the color characteristics of fresh speculum.

*Steel.**—The steel mirror was prepared exactly as described for the steel mirror used as the foundation for the chromium mirror.

*Stellite.**—The specimen of this alloy was polished on a tin lap with fine emery and polished with diamantine on boxwood. The surface was not entirely free from scratches.

Wood's Metal.—An attempt was made to make a mirror of this alloy by pouring the molten metal on plate glass[12] and using the surface of contact without retouching.

Adjustment of Mirrors.—It was necessary to adjust the mirrors carefully to insure that the reflected spectra fell exactly within the diaphragm aperture in front of the plate, and also to make the angle of incidence 45°.

No method of achieving this result was found superior to visual observations on the reflected images from the three mirrors mounted on M, each with three separate adjusting screws. Assuming one mirror to be in adjustment, the others were in adjustment with it when a continuous and straight image of a rod was given by the three adjacent mirrors at all angles of incidence. In practice, one old mirror was left in place while two new ones were adjusted. Even with great care in this adjustment, it was frequently necessary to make small readjustments after test plates had been taken for the reflection of the mirror under consideration.

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* Polished by Mr. David Mann.

The exposure of the photographic plates.—With an apparatus as described, the process of finding the reflecting power at any particular wave-length was to photographically record the spectrum when the plateholder was in the P position, and compare its intensity with the intensity when the plate holder was at the P' position and the light was reflected by a mirror.

To obtain trustworthy numerical results this required that the intensity of the source remain constant in value for the series of exposures. The requirement that the pressure of the gas be lower in the main body of the spectrograph than in the discharge tube coupled with the requirement that there be no window covering the slit necessitated the continuous flow of the gas through the discharge tube. A constant intensity source under those conditions was assumed to be one in which the voltage applied was constant and the pressure regulated to yield a constant current. For a well out-gassed tube this proved to be true under most circumstances. The actual regulating of the pressure to comply with the condition of constant current was tedious, but quite possible with the use of the capillary valve described (Fig. 3). In order that the instantaneous values of the current might never vary more than 5% from an assigned average value, it was essential that the author continually adjust and readjust the flow of gas through the capillary valve.

It was likewise necessary to keep the discharge operating throughout the exposure of a single plate to avoid transient fluctuations when the discharge was started. Thus the exposure of the plate was not undertaken until all the factors of pressure, current, temperature and the like had reached approximately equilibrium values.

Actually in some cases the intensity of the source did change slowly during the course of the exposure of a plate. Such fluctuations were not erratic or sudden, but continuous and very gradual. They were particularly evident with the helium 585 Å line where usually there was a slow increase of effective intensity over a series of exposures. It was easy to correct for such cases by repeatedly applying to the plate some convenient direct exposure, and observing the resultant opacities of the photographic images, either in yielding a curve of the variation of intensity with the time, or showing its constancy.

A typical plate would include in the neighborhood of fifteen exposures one above another. These would cover a region of wave-lengths about 400 Å wide and give data on three different mirrors. After the tube had been out-gassed and then allowed to run for some minutes under conditions chosen for the plate, several exposures would be taken with the plate in the direct (P) position. These would have the same exposure time, but use different apertures of the sectored disk, corresponding to the percentage reflection expected from the mirrors in the apparatus. Next, one of the mirrors would be brought into a reflecting position and the plateholder turned to the P' position (Fig. 1) and exposed for the same length of time as the direct exposures, with the sectored disk out of the path of the light. After the first mirror had been used, one of the direct exposures would be repeated to check the constancy of the source intensity. In turn each of the other two mirrors would be used, with a direct exposure preceding and following each of the mirror exposures.

For each group of three mirrors at least four plates had to be taken to cover the spectral region under examination. Helium was used to produce the 585 Å line. Oxygen was commonly used for the wave-lengths between 1100 Å and 1900 Å, although nitrogen was equally satisfactory. Hydrogen served as a source of intense lines (e. g. 1216 Å) and was useful in the numerous adjustment plates to bring the mirrors into exactly the right position. Hydrogen also was useful to check up on the wave-lengths present in the nitrogen and oxygen spectra.

Wherever possible several plates were taken on each region to provide additional data and a more accurate result. Unfortunately no data are available on the region between 600 Å and 1000 Å, because no gas used presented strong radiation in that region when excited with the direct current discharge.

Photometric measurement of plates.—The measurement of the plates on the thermocouple photometer proceeded according to usual methods. The deflections of the galvanometer were observed for the thermal currents due to the light transmitted by small patches of the plate. For the spectral lines chosen for the calculations, the photographic plate was adjusted in position until the deflection was a minimum. This deflection, the zero point of the instrument, and a deflection representing the energy transmitted by the plate in a neighboring unexposed region were the basis of the calculation of the opacity of the line image. The latter reading on the background of the plate was taken if possible at such a position that it could correct for scattered light a wave-length different from that under consideration.

IV. Photographic Photometry.

Correct Usage of Photographic Plate.—The following is quoted by Prof. Lyman[14] from Fabry and Buisson: "The only correct method of using photography is to attempt to produce two images of equal density on the same plate and with the same time of exposure." This would require here that one of the images be produced by light that has been decreased in intensity to a known percentage of its original value; the other should be produced by the full intensity as reflected from a mirror. With equal densities or opacities the percentage reduction used in the first exposure would measure the reflecting power of the mirror.

Unfortunately there was no simple way of reducing the intensity in a known way for light of these wave-lengths. In all the early work with this apparatus the reduction was accomplished simply by varying the exposure time. The reflecting power at a certain wave-length would be the exposure time of the direct, divided by the exposure time of the reflected spectral line of same opacity (multiplied by 100 for percentage reflecting power).

Reciprocity condition and its failure.—This procedure was not completely satisfactory, for it requires that the opacity of a photographic image is simply a function of the product $I\ t$, where I is the intensity and t the exposure time. This is known as the reciprocity condition, and is known to fail for most emulsions and most wave-lengths except as a first approximation.

The Schwarzschild condition that the opacity is a function of the product $I\ t^p$, where p is an exponent near unity also fails to represent the facts exactly. Jones[14] and his collaborators have shown that under certain conditions p varies between .84 and 1.10, depending on a large number of variables. They have found a relation (the Kron-Halm formula) that does fit the facts for a large number of emulsions. However, no simple method of deriving the constants for this region was available in the present case.

Harrison's work[15] showed that the oiled photographic plate does obey the reciprocity condition for wave-lengths between 2000 Å and 2600 Å. This was not sufficient evidence, however, to permit the numerical results of this investigation to depend upon reciprocity.

Justification for use of Intermittent Sectored Disk.

The apparatus described (Fig. 4) was intended to test whether or not the reciprocity condition holds for wave-lengths shorter than 2000 Å in the case of the oiled emulsion. In addition, it was designed for use in each subsequent measurement of reflecting power.

In a sense however, the sectored disk does not reduce the intrinsic intensity of the beam but merely permits its passage for a certain percentage of the time. It is necessary to justify its use as a means of reducing the intensity of the light.

Davis[16] has treated the intermittent sectored disk and evaluated the "intermittency errors." However, his conclusions do not apply directly here. He contrasted the opacity produced by an intermittent source and a continuous source using the same intensity and actual net time of exposure. In my work, the comparison is to be made between two exposures of the same total elapsed time of exposure, the one at reduced intensity, the other with full intensity but with an intermittent sector rotating to reduce the effective intensity. There is a distinct difference between his case and mine, so it is fundamentally necessary when thinking of intermittency errors to inquire which type of comparison is being made.

Bureau of Standards workers[17] have found the sectored disk as employed here satisfactory and in agreement with other valid methods down to 2500 Å. Baker[18] came to the conclusion that the sectored disk is accurate to 1% in reducing the intensity for photographic work with visible light so long as the flashes produced by the disk occur as often as sixty times per second. It is difficult to understand why one particular speed should mark, as it did, the boundary for all emulsions where the disk became accurate to 1%; it would seem more reasonable if the boundary line depended upon the intensity of illumination used. However, I followed Baker, using exactly sixty flashes per second.

Baly, Morton and Riding[19] have compared the results obtained when an intermittent sectored disk is used with those obtained by accepted valid methods. They worked in the ultra-violet to 2500 Å and found the two methods checking to within the accuracy of their experiment, namely two or three per cent.

The intermittent method of reducing intensities has been compared with calibrated screens by Weinland.[20] In every case he found that the curves of opacity against intensity given by intermittent methods lay between those given by reciprocity and those obtained with the calibrated screens, and nearer the latter. Evidently, the sectored disk as employed in my work is a great improvement over the use of reciprocity as a method of obtaining numerical results from a photographic plate.

V. CALCULATIONS.

The computation of the reflecting power required that the opacity of the reflected image should be matched exactly with the opacity of a direct image. To this end a number of different wave-lengths were chosen, and for each a graph was drawn of opacity against the percentage aperture used in the direct exposures which were all of the same exposure time. The opacities of the corresponding wave-length lines in reflected spectrum could then be used to determine what percentage aperture would be required on the sectored disk to match exactly the reflected spectral line of that wave-length. Repeated for each wave-length under consideration this yielded the numerical reflecting power as a function of the wave-length for the range of wave-lengths covered by the particular plate.

A large part of the work was accomplished without the direct use of the sectored disk. The calculations in those cases consisted in plotting the opacities for a given spectral line against the exposure times producing them. Then with the opacity found for the reflected line of that wave-length, the exposure time of direct exposure could be read off the curve which would produce the same opacity of photographic image as that reflected line. Assuming the reciprocity condition, the reflecting power at that wave-length was the ratio of direct exposure time to the reflected exposure time (multiplied by 100 to give percentage reflecting power).

After the reflecting power for each mirror had been tabulated and averaged at the individual wave-lengths, then an average correction was applied as calculated from twelve plates taken to test the reciprocity condition.

These test plates compared the opacity of lines produced by a direct exposure using the full intensity of the source, with the opacity of lines produced by a direct exposure with the disk operating and the exposure time correspondingly increased. For example, if the 25% opening of the disk was effective then the exposure time was quadrupled. At a particular wave-length, the ratio between these two opacities averaged over a number of plates and taken under various conditions yielded an approximate percentage correction which was applied to the average values of the reflecting power obtained. In addition, these data on the departure from reciprocity were translated into a more familiar form by the computation of the exponent p of the Schwarzschild formula. These average values of p permit comparison of the departure from reciprocity in this region with results obtained in the near ultra-violet and the visible. Furthermore, they show the variation from wave-length to wave-length in the extreme ultra-violet.

VI. SOURCES OF ERROR.

The chief sources of error in this work are as follows: (1) intermittency errors; (2) fluctuation in the intensity of the source of light during the exposure of a plate; (3) variations in the sensitivity of the oiled photographic plate over the area of a single plate; (4) variations in the absorption of the residual gases in the spectrograph; (5) errors introduced by scattered light reaching the mirrors and plate of wave-lengths different from those under consideration; (6) inaccuracies in the photometric measurement of the plates.

The errors due to the inadequacy of the sectored disk as a means of reducing the intensity should be less than 3% according to the work cited of other observers. These errors are, in contrast to the others of this list, distinctly instrumental; i. e. no amount of averaging of a large number of observations can reduce the magnitude of the probable error due to this cause. They are greater in this work than necessary because corrections for lack of reciprocity were perforce approximate where the sectored disk had not been actually used in the exposure of the plate from which the reflecting power data were taken.

It was impossible, in general, to distinguish between sources (2), (3), and (4). The second and fourth have been actually observed where the manipulation of the apparatus had not been up to standard. No direct experiments were made on the variation in the sensitivity of the plates over their areas, but such small plates were used, with comparisons of images not more than one or two centimeters apart, that little trouble was expected from this cause.

Scattered light was bothersome when the spectrographic slit was not clean and when the mirror under examination did not have a good optical surface.

It is difficult to estimate the magnitude of the errors of the photometer used in the measurement of the plates. It would vary with the zero shift of the instrument at the particular time and also depend upon the condition of the photographic plate itself. On the average, its readings were probably good to 3%.

It is possible that single observations on the reflecting power at an isolated wave-length might contain a 10% error. However, with repeated measurements, and with curves averaging the values at neighboring wave-lengths and thus smoothing out the curves, the values given of the reflecting power must be valid to better than 5%. Except for the instrumental error of source (1) still better accuracy might be claimed. For example, the reflecting power of platinum at 585 Å measured on three separate plates 18.5, 18.6, and 18.8%. These would give a probable error of less than 1%.

VII. Results.

Photographic Photometry with the Oiled Photographic Plate.

Direct tests on the behavior of the photographic plate conducted with the sectored disk reveal departures from the reciprocity condition. These are important in some cases, and at other wave-lengths are so small as to be negligible compared to errors from other causes.

The tests were self-consistent in nearly every case in spite of being applied under various conditions on different plates. Some departures from reciprocity of but 1% seemed so persistent in reoccurrence as to be recorded as significant.

By reference to the Schwarzschild condition that the opacity is a function of $I\ t^p$, the average value of p was computed for each wave-length considered, and is plotted in Figure 5. Although I have connected the points by a curve, the connecting curve may, or may not, have any meaning as to the value of p at the intermediate wave-lengths.

A value of p greater than unity at any wave-length indicates that if the reciprocity condition were used in computing the reflecting power, the resulting numerical value would be greater than the true value. Conversely when p is less than unity the reciprocity value for the reflecting power is too low.

In general the departures vary at a given wave-length with the opacity as shown by Jones.[14] It was quite evident that in most cases a greater opacity was accompanied by a larger value of p. The values given in Fig. 5 are average and are intended to be for the opacities actually used in the reflecting power measurements.

The value of p at 1216 Å is larger than at other wave-lengths and the higher value of p seems to persist even for low values of the opacity.

The behavior at the 1151 Å (oxygen) line is most exceptional. Even for high opacities of the photographic image the value of p drops to the lowest value observed. Just what can be the explanation is not evident, but the effect may be caused by the fluorescent action of the sensitizing oil.

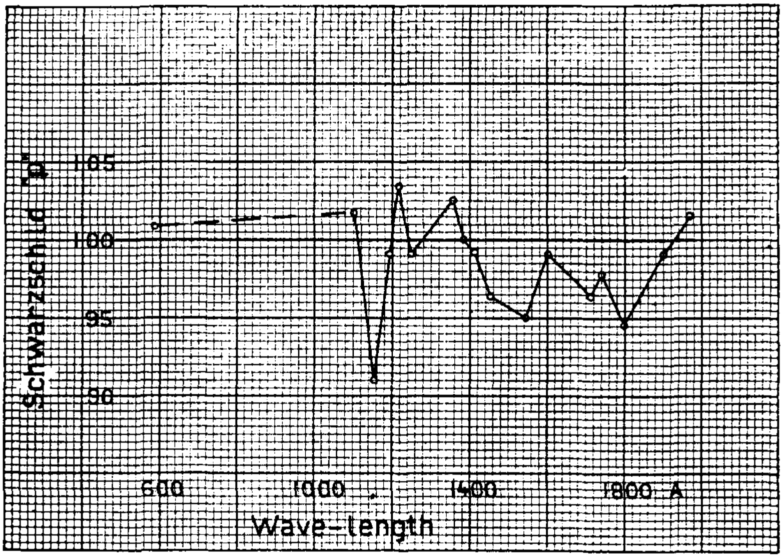

Fig. 5.

Applying the correction indicated at 1151 Å and 1216 Å has served to smooth out the reflecting power curves in that region. When reciprocity was assumed the curves for all materials showed a dip downwards at 1151 Å and up at 1216 Å, the corrections have made the results seem more reasonable in that the values at those two neighboring wave-lengths became very nearly the same. On some curves the former effect is still evident, probably because the corrections were not exact.

It is clear that the value of p is near enough unity at certain wave-lengths so that this oiled photographic plate might be used at those wave-lengths under the assumption of the reciprocity condition. In general, however, wherever an accuracy better to that 5% is sought these departures from reciprocity can not be neglected. The only valid method must still be one where known reductions of intensity are applied to each and every plate used in the measurements.

Reflecting Power Results.—The results to be given cover the seventeen substances and twenty-five mirrors investigated. With minor exceptions, the qualitative work of Gardner[2] agrees with my work. In general, the numerical values at 1850 Å given by Hulburt[6] are higher than mine.

Pfund's work[3] agrees with the values given here for crystalline quartz, glass, speculum and silver while there is some disagreement on gold and platinum. The work of Lewis and Hardy[5] near 1850 Å is consistent with my results for the metals they studied. Their values for the reflecting powers of other materials do not agree with mine.

While I paid considerable attention to the value of the reflecting power at 585 Å, the shortest wave-length reached, still the exact shape of the reflecting power curves at that point is unknown. This is unavoidable inasmuch as no suitable source was available for wave-lengths between 585 Å and 1000 Å. The curves are drawn with broken lines in that region to remind the reader of that fact. The reflecting power continues to decrease with shorter wave-lengths.

Aluminum.—The reflecting power curve of a sputtered aluminum surface is shown in Fig. 6. At 585 Å it shows a 5% reflecting power which apparently remains constant until 1400 Å, from which wave-length it rises to 14% at 1850 Å.

These values are consistent with Gardner's conclusions. Hulburt's value of 23% at 1850 Å is much higher than mine. Nutting's[21] prediction of a 65% reflection at that point must be in error.

Beryllium.—The reflection of a sputtered beryllium surface is shown in Fig. 9. The work of Coblentz and Stair[22] gives a 57% reflecting power for beryllium at 2500 Å with a curve that rises towards shorter wave-lengths. My work, however, reports a relatively small reflecting power at 2000 Å and shorter wave-lengths. Beryllium is unique in showing a deep minimum in reflection at 1640 Å. Its reflecting power is increasing towards the shorter wave-lengths rising to 9.9% at 585 Å.

With only a reflecting power of one per cent at 1640 Å, according to classical reflection formulae the index of refraction must be nearly unity at that point and k, the absorption coefficient must be small. Probably the index of refraction of beryllium is passing through the value unity at that wave-length. If that is the case, then k is 0.27 there.

Brass.—The reflecting power (Fig. 7) of brass polished on jasper remains at a low value throughout the extreme ultra-violet. At 585 Å it is 5%, falling to 4.1% at 1216 Å, rising to 7% at 1600 Å and falling again to 5.9% at 1850 Å. Nutting[21] gave a value of 65% at that wave-length.

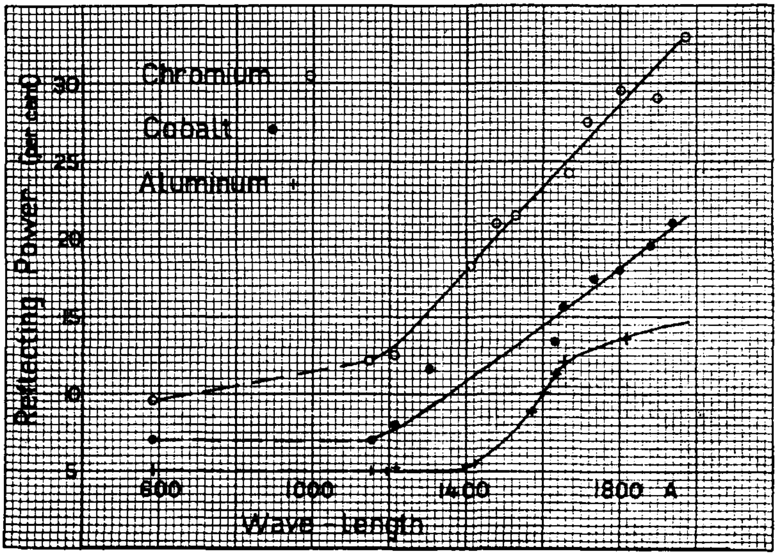

FIG. 6.

Chromium.—The reflecting power of the chromium mirror (Fig. 6) (electrolytically deposited on steel and touched up with diamantine) is 9.6% at 585 Å, rises to 13% at 1216 Å and at wave-lengths longer than 1400 Å has a higher reflecting power than any substance studied. At 1850 Å my value of 30% checks Hulburt's value. Coblentz and Stair[22] not only report a high reflecting power for chromium in the ultra-violet but find that it retains this property even after prolonged exposure to ultra-violet light.

Cobalt.—The reflecting power of a mirror of cobalt metal (Fig. 6) varies from 7% at 585 Å to 7.8% at 1216 Å to 19.0% at 1850 Å.

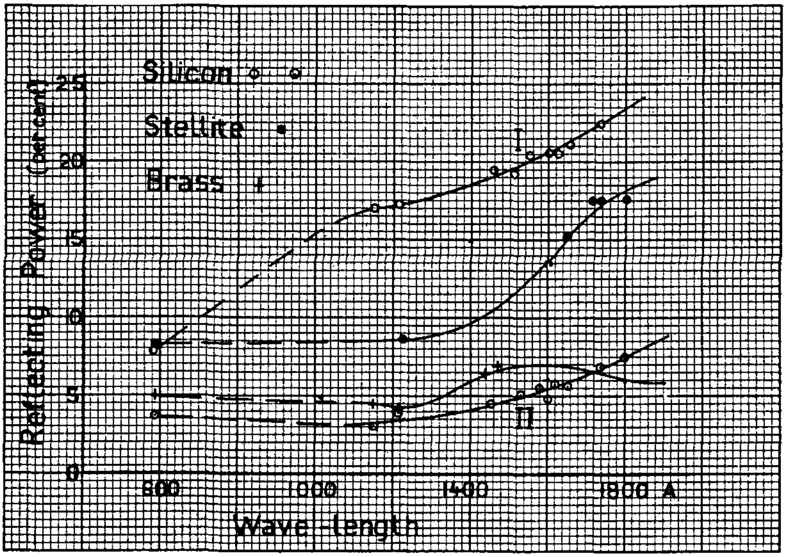
Silicon ○
Stellite ●
Brass +
I
II
Reflecting Power (per cent)
25
20
15
10
5
0
600
1000
1400
1800 A
Wave-length

FIG. 7.

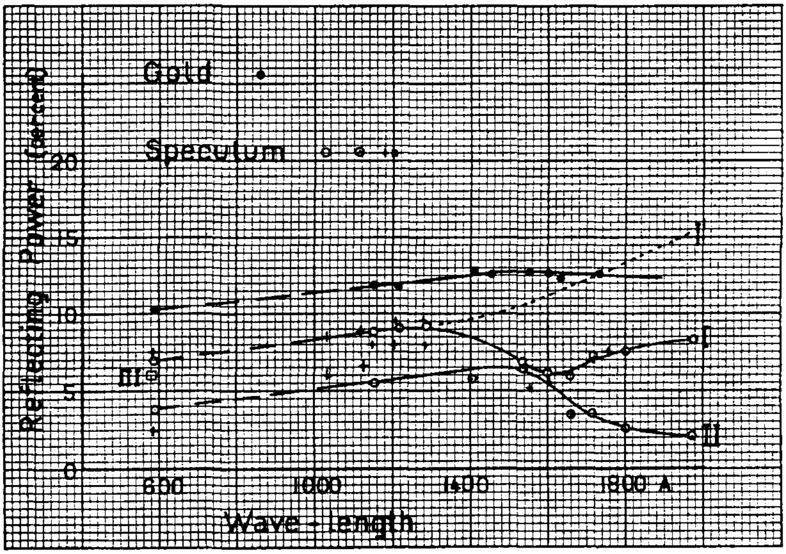
Gold ●
Speculum ○ ○ +
I
I
II
III
Reflecting Power (per cent)
20
15
10
5
0
600
1000
1400
1800 A
Wave-length

FIG. 8.

This latter figure is much less than the 30% figure of Hulbert's at that wave-length.

Gold.—The sputtered gold mirror (Fig. 8) has a high reflecting power at 585 Å of 10.3%. However it does not increase above 12.8% in the entire region. My work agrees with Gardner that gold is superior to speculum particularly at the shorter wave-lengths. Hulburt ascribed a reflecting power of 14% to gold at 1850 Å compared with 12.5% in my work. Pfund's value of 6.3% is much less than the 12% for the same region in my work.

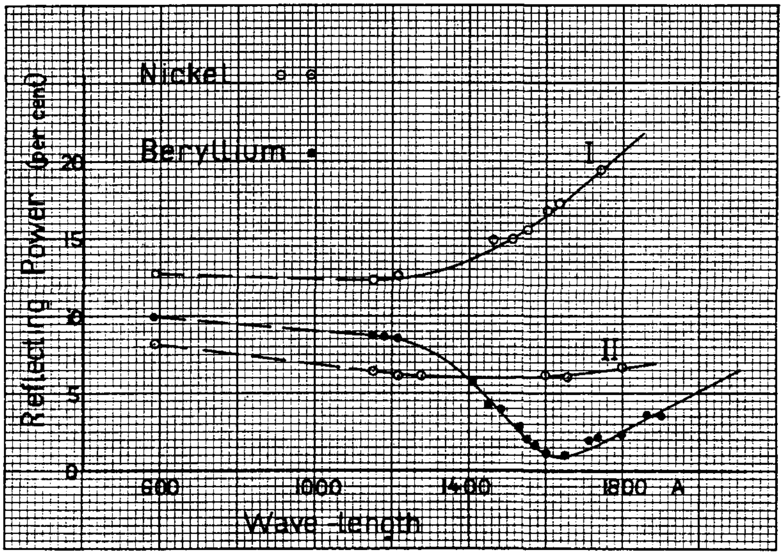

FIG. 9.

Nickel.—The results on two sputtered nickel mirrors are shown in Fig. 9. The value of 12.6% for the reflecting power at 585 Å gives fresh nickel (curve *I*) the position second to platinum among the best reflectors at that short wave-length. Even the two year old sputtered film (curve *II*) possesses a reflecting power of 8.0% at 585 Å which is as good as the best speculum surface observed. Since the shape of curve *II* is different from that indicated in curve *I* it is likely that the sputtered film had oxidized in its long exposure to the air.

Gardner gave nickel a slight superiority over speculum at his shorter wave-lengths, which is true here. Hulburt's value of 28% at 1850 Å is rather higher than my 21.5%.

Platinum.—Four different sputtered platinum mirrors are covered in the data of Fig. 10. Curve *I* is for a fresh, bright surface and at shorter wave-lengths is far superior to any other mirror studied. This value of 18.6% at 585 Å was checked repeatedly and is the average of data from five plates. When the attempt was made to check this result on another surface, freshly sputtered, a good bright surface was not obtained. But even the curve for that mirror (curve *II*) is parallel to the first and the numerical values are much higher than for other materials. Curve *III* covers a mirror sputtered at the same time as the second specimen but on which a bluish film had formed due probably to the fuming of the soft wax with which it was mounted. Curve *IV* is for a surface sputtered nearly two years prior to the time of this test, and spotted accidentally at that time with phosphorus pentoxide. Even with that abuse, its reflecting power at 585 Å is as high as for the best speculum!

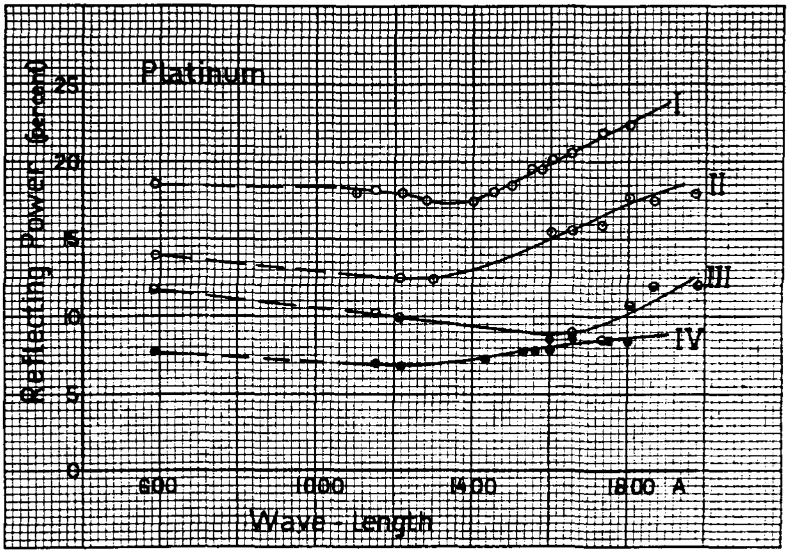

FIG. 10.

It is interesting to note that the first successful test of reflecting power taken with this apparatus was made with the mirror of curve *IV* when it was new and unspotted and at the wave-length 585 Å. No accurate means of controlling the intensity were available, but an attempt was made to keep the average intensity constant over the very long exposures then taken. After a year had passed, the plate was run through the photometer and the estimate made that the reflection at 585 Å would be 18.4%. This compares very favorably with the careful measurements ten months later giving the value 18.6%. There was some evidence on the early plate, which recorded the 738 Å line of neon, that platinum has a maximum in its reflecting power between 600 Å and 1000 Å rising to 25% in that region. This has not been verified.

Gardner's conclusion that the reflecting power of platinum is increasing with respect to speculum for wave-lengths shorter than 1200 Å agrees with my work. Pfund's value of 8% for the spectral region he investigated is much lower than the 18% on my curve *I*. At 1850 Å the value here is 23.5% whereas Hulburt gave 31% and Lewis and Hardy 21%.

Silver.—It is well known that silver tarnishes rapidly under exposure to ultra-violet light. The same effect here made it practically impossible to get results on a fresh surface. By the time an adjustment plate could be taken the specimen was no longer fresh. Fig. 11 gives my interpretation of the data. Curve *I* is intended to describe the reflection of a fairly fresh surface, the dotted portion of it is unsupported by experiment. Curve *II* is for the same surface in a badly tarnished condition, due almost entirely to its exposure to the extreme ultra-violet during adjustment and measurements.

This work agrees with Gardner's in showing silver to be a poor reflector in this region. Pfund's value of 5.1% for the wave-lengths just short of 1200 Å is exactly the value on curve *I*. Hulburt's value of 18% at 1850 Å compares with 12% on curve *I* and 7.5% on curve *II*.

Silicon.—Two silicon mirrors were measured (Fig. 7). One was freshly sputtered (curve *I*) while an old mirror on glass of uncertain origin was also tested (curve *II*). The latter was not very clean nor was the silicon film very thick. The new film (curve *I*) gives a reflecting power of 7.8% at 585 Å and rises rapidly to 17% at 1200 Å and 24% at 1850 Å.

The qualitative statement of Gardner is verified that silicon reflects about twice as well as speculum at the longer wave-lengths and falls to almost the level of speculum at 1100 Å. Hulburt's value of 60% at 1850 Å is very much greater than my value. Lewis and Hardy's value of 31% is closer to mine. A thicker film or a good solid mirror might give higher values than mine.

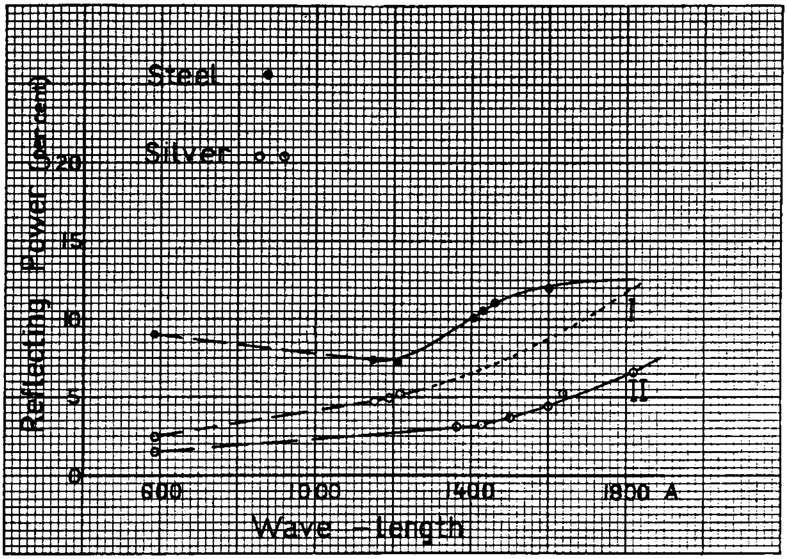

Fig. 11.

Speculum.—Reflection by speculum mirrors from Fecker was given considerable study (Fig. 8). Particular attention was given the reflection at 585 Å. Values all the way from 2.5% to 7.5% were obtained there. Such variation could entirely be accounted for by the tarnishing of the surface. Even a freshly sputtered surface gave a reflection of but 6% at 585 Å. This point is indicated by the square and marked *III*.

The first Fecker mirror was first measured in a tarnished condition and was then repolished a number of times. An average of some of the data on it is indicated by the crosses. At 585 Å only extreme values are shown. Curves *I* and *II* are for the second mirror from Fecker. Curve *I* gives the data for it freshly polished, but slightly tarnished with a light bluish film caused probably by the fuming of the soft wax mounting. Curve *II* is for the same mirror two weeks after polishing on which the tarnish was very apparent. The dotted curve *I′* is drawn to estimate the reflecting power for clean polished speculum. This is not supported by direct experimental data except the evidence from curves *II* and *III* of platinum.

Curves *I* and *I′* correspond to Gardner's comparison of speculum to other substances. Hulburt's results are in accord with these since he found values ranging from 20% to 4% at the 1850 Å wave-length. Lewis and Hardy's result of 10% at that wave-length is in accord with curve *I*. Pfund's value of 5.3% for the wave-length region just below 1216 Å conforms very closely to the values of curve *II*.

Steel.—The reflecting power of steel (Fig. 11) decreases from 9% at 585 Å to 7.2% at 1216 Å and then rises to 12.2% at 1800 Å. This corresponds to Gardner's statement that steel is equal to or better than speculum at the longer wave-lengths, but inferior at the shorter. However, at the still shorter wave-length employed here steel becomes again superior. Hulburt found a value of 16% for steel at 1850 Å compared to mine of 13%.

Due to adjustment difficulties, these data are the results of single observations and are not to be considered as up to the usual accuracy of this work.

Stellite.—The stellite mirror (Fig. 7) shows a reflecting power of 8.3% at 585 Å rising to 8.6% at 1216 Å and then to 18.2% at 1800 Å. This compares favorably with Gardner's conclusion that stellite is a better reflector than speculum. Hulburt's value of 30% is much greater than mine of 18.6% at that point.

The fact that the reflecting power curve for stellite is almost the same as for cobalt may indicate that cobalt must be the constituent of stellite playing the important role in its reflecting power.

Wood's Metal.—No numerical data were obtained upon the mirror of this alloy. I wished to test roughly its reflecting power because of the high value given at 2573 Å by Meier.[12] A single plate was taken in the region of 1200 Å. It was evident from that plate that the reflecting power there is not more than 8%.

Materials other than metals were tried to test the modern grating materials of glass and quartz. A test was made of fluorite because its index of refraction is known in this region.

Fluorite.—Despite the fact that the reflection from the specimen of fluorite was very faint and hazy in the visible, it was finally placed in adjustment. The reflected spectra were all rather fuzzy as a result of the scratches and possible lack of flatness of the surface. It is not surprising to find low reflection in the extreme ultra-violet.

Both the photometer and the eye detected the fact that fluorite reflects very much better in the region around 1100 Å than at longer and shorter wave-lengths. The reflecting power curve without correction for the fuzziness of the reflected spectral lines is shown in Fig. 12. The maximum occurs at 1125 Å with a value of 6.3%. The reflecting power falls to 2.8% at 1850 Å and 3.0% at 585 Å.

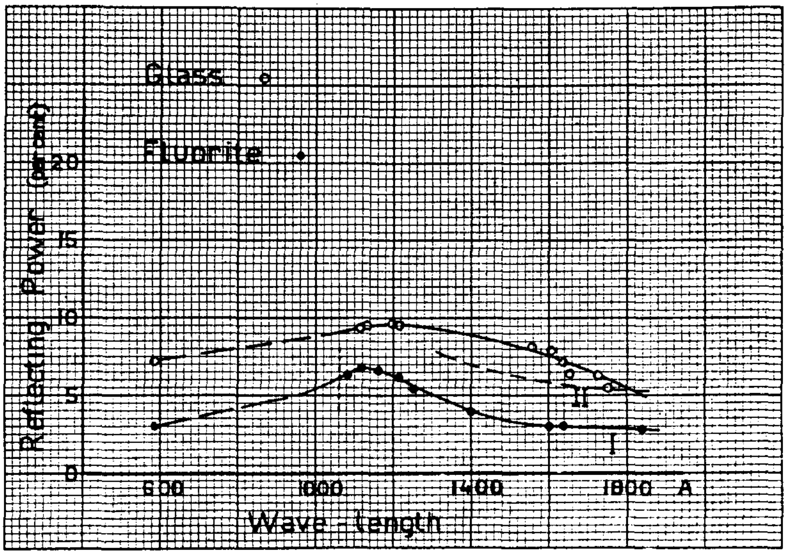

Fig. 12.

A dispersion curve[23] to fit index of refraction data requires an absorption band at 1056 Å. Depending upon the value of the absorption coefficient, we would expect a maximum in the reflecting power at some wave-length just longer than 1056 Å. This is consistent with the observed maximum at 1125 Å.

Handke[24] has computed the index of refraction of fluorite down to 1311 Å. Assuming equal parallel and perpendicular polarization components incident on the mirror, it is possible to apply Fresnel's reflection formula and compute the reflecting power for 45° incidence. I have plotted it as curve *II* shown as a broken line. This is very closely parallel to the experimental curve, and as might be expected the experimental curve falls below the theoretical curve.

Lewis and Hardy reported an 8% reflection at 1850 Å whereas the theoretical curve gives 5.5% and my experimental value is 2.8%. Lewis and Hardy ascribed their deviation from theory to a high value of the absorption coefficient which would invalidate Fresnel's formula. Both the fact that fluorite is very transparent at that point, and the fact that Fresnel's formula gives a curve so near to the shape of mine would indicate that their explanation was incorrect.

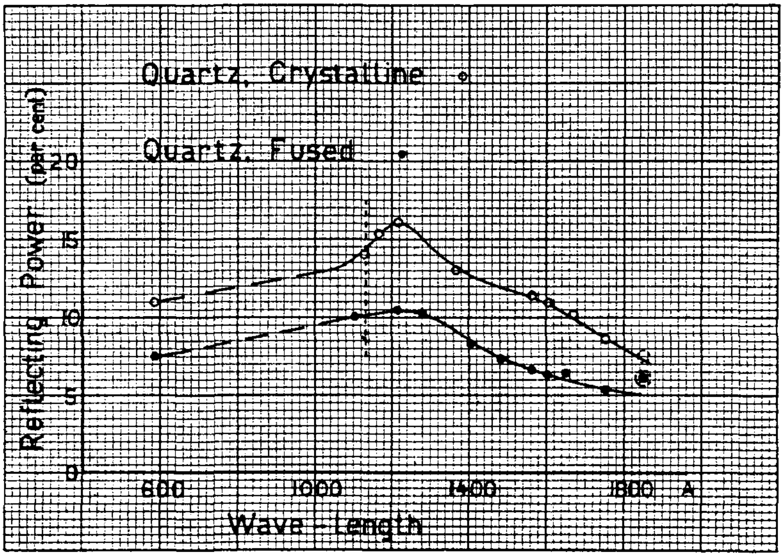

FIG. 13.

Glass.—The reflecting power of glass (Fig. 12) rises from 7.3% at 585 Å to 9.6% at 1200 Å and drops to 5.1% at 1800 Å.

Pfund's value of 8.5% for the wave-lengths just short of 1200 Å is lower than mine which go from 8.9% at 1000 Å to 9.6% at 1200 Å. Lewis and Hardy give 13.5% reflection for "ordinary glass" at the 1850 Å region. My value of 5.0% is clearly lower.

Quartz.—The reflecting power of crystalline quartz (Fig. 13) starts at 11.0% at 585 Å and increases to 16.0% at 1216 Å and then decreases to 8.0% at 1800 Å. Fused quartz behaves similarly with lower values throughout. It varies from 7.5% at the lower wave-length to a maximum of 10.5% and drops to 5.2% at 1800 Å.

TABLE I.

Reflecting Power in Per Cent.

	Wave-length			
Substance	585 Å	1150 Å	1500 Å	1800 Å
Aluminum	5.0	5.0	7.0	13.5
Beryllium	9.9	8.7	3.4	2.5
Brass	4.9	4.5	6.8	6.0
Chromium	9.6	12.2	20.7	28.5
Cobalt	7.0	7.0	12.3	17.0
Fluorite	3.0	6.7	3.3	2.8
Glass (spectacle lens blank)	7.3	9.1	8.4	5.3
Gold	10.3	11.8	12.8	12.5
Nickel freshly sputtered	12.6	12.2	14.7	20.5
old sputtered	8.0	6.3	6.0	6.5
Platinum freshly sputtered	18.6	18.2	18.6	22.1
imperfect freshly sputtered	13.9	12.6	13.8	17.2
tarnished sputtered	11.7	10.2	9.0	10.2
old and spotted sputtered	7.8	7.0	7.8	8.8
Quartz, crystalline	11.0	14.9	11.8	8.0
Quartz, fused	7.5	10.3	7.1	5.2
Silver fresh	2.5	4.8		
after exposure	1.5	2.7	3.7	6.0
Silicon freshly sputtered	7.8	16.9	19.4	23.3
old	3.7	3.2	4.7	7.5
Speculum fresh	7.5			
sputtered	6.0			
badly tarnished	2.5			
light tarnish	3.8	5.5	6.8	2.5
repolished	7.0	8.8	7.3	7.5
Steel, carbon tool	9.0	7.4	11.4	12.7
Stellite	8.3	8.5	11.2	18.2
Wood's Metal		7 (?)		

In the case of quartz, we have the value of the index of refraction only to 1850 Å. This gives a numerical check with theory only at that point. By applying the Fresnel formula for the reflection of transparent substances (assuming equal polarization components) I find that crystalline quartz should have a reflection of 7.5%, whereas my data give a value of 7.2%. With fused quartz the agreement is not quite so good: a theoretical value of 6.1% as against 5.0% by experiment.

Dispersion formulae have been fitted to the values for the index of refraction of crystalline quartz.[25] These require the introduction of an absorption band at 1130 Å. This wave-length is shown by the vertical dotted line in Fig. 13. The maximum in the reflecting power at 1220 Å satisfies the condition that there should be a maximum in reflection at the long wave-length side of the absorption band.

Pfund's value of 13.5% agrees with mine for crystalline quartz in that my curve rises from 13.0% at 1025 Å to 16.0% at 1216 Å. Lewis and Hardy's value of 10% at 1850 Å is greater than my value of 7.0%.

My results are a confirmation of Prof. Lyman's[26] conclusions in regard to the relative reflection of glass, quartz and speculum when used in gratings. He found glass and quartz superior to speculum at the shorter wave-lengths. He indicated that quartz was hardly any better than glass. Since his tests were on a grating ruled on fused quartz, his practical work agrees with my measurements.

VIII. Conclusions.

It is quite evident that a number of factors affect the values of the reflecting powers of substances and their variation with the wave-length. Clearly surface conditions are important and are particularly potent in reducing the absolute value of the reflecting power, and in changing the shape of the curves as functions of the wave-length.

This variation with surface conditions is amply illustrated by the results on speculum (Fig. 8), silver (Fig. 9) and platinum (Fig. 11). In the case of speculum and platinum the effect was partly due to the fuming of the heated soft wax used in mounting the mirrors. This same soft wax was extensively used in the apparatus for the sealing of flange plates and windows to the spectrograph. Probably the slow fuming at ordinary temperatures accounts for a part of the tarnishing of a speculum grating in use.

An attempt was made to discover which ingredient in this soft wax was responsible. As far as visual observations could tell, the bees wax and the Venice turpentine were equally guilty when permitted to fume at equal temperatures on equally well polished speculum mirrors.

The arrangement of the molecules in a substance may be of prime importance in determining the value of the reflecting power in the extreme ultra-violet, whereas the nature of the molecules may determine the shape taken by the curve of reflecting power against wavelength.

This is shown by the relation between the curves for crystalline quartz and fused quartz. Both are SiO_2 and the shapes of the curves are quite similar. However the arrangement of the molecules in the two cases is different and my curves show that crystalline quartz is superior at all wave-lengths.

Even in mixtures of various materials it seems that one of the constituents is inclined to dictate the shape of the reflecting power curve. In my results this is shown by the similarity of the curves for glass and fused quartz and for stellite and cobalt.

This work coupled with that of Pfund's[4] gives strong evidence for the fact that dispersion formulae of transparent substances determine with fair accuracy the positions both of the absorption bands and the maxima in the reflecting power of these substances. On this basis, diamond should not only have a maximum in its reflecting power in the neighborhood of 1400 Å, but should (due to its high index of refraction) have a higher reflecting power than any other substance studied at these wave lengths.

The comparative data on reflecting power are shown in Table I. It is seen that platinum is the best reflector at the shorter wave-lengths with nickel, crystalline quartz and gold following in order. On account of the great permanence of a polished surface of chromium and relatively good reflecting power, it should be a useful reflecting material in this region.

The photometric work with the oiled photographic plate has shown that the reciprocity condition may be depended upon for approximate results but that it can not be used in more accurate work.

I wish to express my gratitude to Mr. David Mann, chief mechanician of the Jefferson Laboratory for his careful work in the preparation of the apparatus for this undertaking.

It is a pleasure to thank Prof. Lyman for suggesting this problem and maintaining a constant and helpful interest in all its details.

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AN EQUATION OF STATE FOR GAS MIXTURES. II. A STUDY OF THE METHODS OF COMBINATION OF THE CONSTANTS OF THE BEATTIE-BRIDGEMAN EQUATION OF STATE.

By James A. Beattie and Shikao Ikehara.

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(Contribution from the Research Laboratory of Physical Chemistry,
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1. INTRODUCTION.

THE classical method of treating the thermodynamic properties of gas mixtures is to combine from the beginning of the discussion the methods of thermodynamics and statistical mechanics. In this manner van der Waals,[1] and van Laar and Lorenz[2] gave relations for the properties of gas mixtures based on the ideas from which van der Waals' equation of state was derived; and Keyes[3] obtained relations by use of the Keyes[4] equation of state.

Recently there has been proposed another method of approach, which involves the separation of the thermodynamic and statistical treatments until the end of the discussion when the general equations derived by thermodynamic methods are integrated by use of an equation of state for gas mixtures. Some assumption or assumptions are necessary as a starting point for the thermodynamic discussion and Gillespie[5] has shown that general relations for the isothermal variation of certain properties of gas mixtures can be derived from the assumption of Dalton's law of partial pressures at low pressures. De Donder,[6] Van Lerberghe[7] and one of the authors[8] have also treated this problem.

It has been found[9] that two assumptions are required in order to derive expressions for the variation of the thermodynamic properties of gas mixtures with both temperature and pressure. The equations so obtained may be called the general thermodynamic relations since they depend only on the two assumptions and the general laws of thermodynamics. In order to evaluate the partial derivatives which each of these equations contains, it is necessary to have available an equation of state for gas mixtures and such a relation must necessarily depend to a greater or less extent on the methods of statistical mechanics.

In the present paper an equation of state for gas mixtures based on the Beattie-Bridgemen equation of state is considered from the standpoint of the recent experimental data.

2. PREVIOUS INVESTIGATIONS.

We are concerned here with the methods that have been proposed for calculating, from data on the pure component gases, the pressure (or volume) of a mixture of gases when the volume (or pressure), temperature and composition are given.

(a) *Simple Additive Relationships.*

There are four additive rules for the treatment of gas mixtures which should be mentioned:

1. *Dalton's law.*[10] This is usually stated: The pressure of a mixture of gases is equal to the sum of the pressures of the component gases existing each by itself at the temperature and in the total volume of the mixture. This may be called the law of the additivity of pressures at constant temperature and volume. It is well known that the law does not hold for the successive additions of portions of a pure gas to a given volume unless the gas follows Boyles' law.

On the basis of Dalton's law, the equation of state of a gas mixture would be obtained by adding the equations of state for the component gases in the following manner:

$$p = f_1(V, T, n_1) + f_2(V, T, n_2) + \cdots \tag{1}$$

In this relation p is the total pressure of the gas mixture; V, T, n_1, n_2, $\cdots$ are the total volume and the temperature of the mixture and the number of moles of the Gases 1, 2, $\cdots$ composing the mixture; and

$$p_i = f_i(V, T, n_i) \qquad i = 1, 2, \cdots$$

are the equations of state of the pure gases.

When applied to ideal gases, Dalton's law gives the result that:

$$p_i = px_i$$

where p is the total pressure of the mixture and x_i the mole fraction of Gas i in the mixture. The product px_i is usually called the "partial pressure."

2. *Gibbs-Dalton law.* From a consideration of vapor pressures, Gibbs[11] proposed a modification of Dalton's law: The pressure of a mixture of gases is equal to the sum of the pressures of the component gases existing each by itself at the temperature and with the same value of its chemical potential as in the mixture. Lurie and Gillespie[12] were the first to make a study of the Gibbs-Dalton law. They pointed out that this law leads to the same expression as Dalton's law, equation (1), for the equation of state of a gas mixture.

3. *Amagat's law.* From a study of his measurements of the compressibilities of oxygen, nitrogen and air, Amagat[13] concluded that: The volume of a mixture of gases is equal to the sum of the volumes of the component gases existing each by itself at the temperature and under the total pressure of the mixture. This may be called the law of the additivity of volumes at constant temperature and pressure. Since volume is an extensive property, Amagat's law evidently holds for the "mixing" of various portions of a real gas each being at the same temperature and pressure.

Amagat's law leads to an equation of state for a gas mixture obtained by adding the equations of state of the component gases in the following manner:

$$V = F_1(p, T, n_1) + F_2(p, T, n_2) + \cdots \tag{2}$$

In this relation V is the total volume of the gas mixture; p, T, n_1, n_2, $\cdots$ are the total pressure and the temperature of the mixture and the number of moles of the Gases 1, 2, $\cdots$ composing the mixture; and

$$V_i = F_i(p, T, n_i) \qquad i = 1, 2, \cdots$$

are the equations of state of the pure gases.

4. *Lewis and Randall rule.* On the assumption that gas mixtures could be considered as perfect solutions, Lewis and Randall[14] proposed: The fugacity of a gas in a mixture is equal to the product of the fugacity of the pure gas existing at the temperature and under the total pressure of the mixture multiplied by the mole fraction of that gas in the mixture. Gillespie[5] has shown that this rule applies only when Amagat's law holds for the gas mixture. Hence the Lewis and Randall rule leads to the equation of state (2) for gas mixtures.

Thus the first two laws result in an equation of state of the type (1) for a mixture of gases, while the latter two give an equation of the type (2). Either Dalton's or Amagat's law can be used wtihout the aid of an equation of state provided that compressibility data on the pure gases are available.

It has been generally accepted[15] that Amagat's law gives more satisfactory results than Dalton's law for the permanent gases. Lurie and Gillespie[12] have shown that the Lewis and Randall rule gives more satisfactory results than the Gibbs-Dalton law when applied to the calculation of the "equilibrium pressure" of ammonia in mixtures of nitrogen and ammonia. Keyes and Burks[16] found that Amagat's law is a better approximation than Dalton's law of "partial pressures" in terms of weight fraction (rather than mole fractions) for mixtures of nitrogen and methane. Masson and Dolley[17] found that Amagat's law gave a better representation of their measurements on argon-oxygen mixtures than Dalton's law although the reverse was the case for argon-ethylene and oxygen-ethylene mixtures. All of these comparisons show that Dalton's and Amagat's laws each give an increasingly good representation of the experimental data as the pressure is diminished, but that they may lead to large errors at moderately high pressures especially when one of the gases is much more compressible than the other.

(b) *The van der Waals Equation of State.*

There have been many investigations concerned with the representation of the pressures of gas mixtures by use of van der Waals' equation of state:[18]

$$p = \frac{RT}{v - b} - \frac{a}{v^2} \tag{3}$$

in which R is the ideal gas constant, a and b constants for each gas, and v the volume of a unit mass, say one mole, of the gas.

General considerations indicate that the equation of state of a mixture of gases which do not react chemically should be of the same form as that for the pure component gases and the same conclusion is reached by use of statistical mechanics.[19] Thus from the standpoint of empirically representing the compressibility data, it should be possible to select values of a and b which give as satisfactory a result for a mixture of gases as for the pure constituent gases. Since the time of van der Waals it has further been the expectation that the values of the parameters for any given gas mixture could be calculated from the constants of the pure component gases and the composition of the mixture. General considerations and statistical mechanics again concur in indicating that each of the constants a and b should be combined with the composition in the most general quadratic manner. Thus for the b constant we may write:

$$b_x = b_1x_1^2 + 2b_{12}x_1x_2 + b_2x_2^2 \tag{4}$$

In this relation b_1 and b_2 are the values of the b constant for the pure Gases 1 and 2, b_x the value of this constant for a binary mixture of these gases the composition of which is expressed in terms of the mole fractions x_1 and x_2, and b_{12} a so-called "interaction constant" which arises from the interaction of unlike molecules. Thus when applying equation (3) to the gas mixture we can replace b by b_x and a by a_x, using for v the volume of an average mole of mixture.

Several methods for evaluating the interaction constants have been suggested, the two simplest of which are that they may be taken as the arithmetic, or as the geometric mean of the corresponding constants for the pure gases. Thus for the b constants we may write:

$$b_{12} = \tfrac{1}{2}(b_1 + b_2) \tag{5}$$

or:

$$b_{12} = (b_1b_2)^{1/2} \tag{6}$$

When these are substituted into (4) there results for b_x:

$$b_x = b_1x_1 + b_2x_2 \tag{7}$$

or:

$$b_x^{1/2} = b_1^{1/2}x_1 + b_2^{1/2}x_2 \tag{8}$$

The first of these methods for computing b_x, equation (7), will be called linear combination of constants and was used to some extent by van der Waals and by Berthelot[20] for the b constant; the latter method, equation (8), will be called linear combination of $b^{1/2}$ or linear square root combination and was used by Galitzine[21] and by Berthelot[20] for the cohesive constant a.

On the assumption that the molecules are elastic spheres and that the distance of closest approach of the centers of any two molecules is the sum of the radii of the two molecules in question, Lorentz[22] derived for the b_{12} interaction constant the value:

$$b_{12}^{1/3} = \tfrac{1}{2}(b_1^{1/3} + b_2^{1/3}) \tag{9}$$

Thus:

$$b_x = b_1x_1^2 + \tfrac{1}{4}(b_1^{1/3} + b_2^{1/3})^3x_1x_2 + b_2x_2^2 \tag{10}$$

We shall call this the Lorentz method of combination. It has been quite generally employed[23] for b_x. It is questionable however if the b constant should be linked too intimately with the distance of closest approach of the molecules. On the basis of Phillips'[24] view, any kind of interaction between the molecules of a gas would give rise to a b term; that is, the pressure of the gas would be increased by any type of interaction, regardless of whether the interaction is due to attractive or repulsive forces, regardless of the law of the forces and further, independent of the size of the molecules, which may be infinitesimal.

Because of the failure of van der Waals' equation to give even an approximate representation of the compressibility of pure gases over a wide range of temperature and density, it has never been applied to compressibility data on gas mixtures except[23] at relatively low pressures.

(c) *The Keyes Equation of State.*

The first quantitative treatment of gas mixtures at relatively high pressures was by means of the Keyes equation of state:[4]

$$p = \frac{RT}{v - \beta e^{-\alpha/v}} - \frac{A}{(v + l)^2} \tag{11}$$

in which R is the gas constant and α, β, A and l constants for each gas. Lurie and Gillespie[12] applied this equation to the calculation of the equilibrium pressures of ammonia in a mixture of ammonia and nitrogen to 60 atmospheres at 45° C. They used linear combination for each of the constants R, α, β, $A^{1/2}$ and l as suggested by Keyes and stated that the computed values agreed with the experimental data possibly to within the experimental data. Keyes and Burks[16] measured the compressibility of mixtures of nitrogen and methane to about 300 atmospheres and from 0 to 200° C. They determined the values of the four adjustable constants of (11) for each of the mixtures investigated, thus definitely proving that the compressibility of the mixtures and of the pure gases can be represented by the same type of equation of state. They further found that each of the constants as determined from the data on the mixtures could be satisfactorily calculated from the values of the constants for the pure gases and the composition by the method mentioned above.

(d) *The Beattie-Bridgeman Equation of State.*

One of the authors[25] has applied to gas mixtures the Beattie-Bridgeman[26] equation of state:

$$p = \frac{RT(1-\varepsilon)}{v^2}[v+B] - \frac{A}{v^2} \tag{12}$$

$$A = A_0(1 - a/v)$$

$$B = B_0(1 - b/v)$$

$$\varepsilon = c/vT^3$$

in which R is the ideal gas constant and A_0, a, B_0, b and c are constants for each gas. The pressures of the nitrogen-methane mixtures as measured by Keyes and Burks are well represented when the values of the parameters for the mixtures are computed by linear combination of each of the constants R, A_0,$^{1/2}$ a, B_0, b and c. The values of the constants of the pure gases used were those determined from the data of Smith and Taylor[27] on nitrogen and of Keyes and Burks[28] on methane; the former having used the same apparatus for the compressibility measurements on nitrogen as the latter used for methane and the mixtures.

(e) *Other Methods.*

Several other methods of attack on the problem of the equation of state of gas mixtures have been made. Thus Lennard-Jones and

Cook[29] have shown that the second virial coefficient should be quadratically combined in the manner of equation (4) but that the interaction constant is not related in any simple manner to the coefficients for the pure gases. A relation for the interaction constant is given in terms of the force constants appearing in the equation representing the attractive and repulsive forces between molecules of unlike type. The relations obtained are too involved for general use.

Deming and Shupe,[30] extending a method suggested by Kleeman,[31] have calculated the pressures of the binary mixtures of nitrogen and methane investigated by Keyes and Burks by combining each of the coefficients in the general virial equation:

$$p = \frac{A_1}{v} + \frac{A_2}{v^2} + \frac{A_3}{v^3} + \frac{A_4}{v^4} + \cdots \tag{13}$$

according to the method:

$$A_{mx} = [\Sigma x_i \varepsilon_{mi}(\varepsilon_{mi}A_{mi})^{1/m}]^m \tag{14}$$

where A_{mx} is the mth virial coefficient of the mixture; A_{m1}, A_{m2}, $\cdots$ the mth coefficients of the pure Gases 1, 2, $\cdots$; x_1, x_2, $\cdots$ the mole fractions of the gases in the mixture; and $\varepsilon_{mi} = +1$ or -1, whichever is required to make the product $\varepsilon_{mi}A_{mi}$ positive. The summation extends over all the gases in the mixture. The method is applicable when the values of the virial coefficients for the pure components have been determined at a single temperature only. Deming and Shupe found that this method does not give quite so good an overall representation of the nitrogen-methane data as the Beattie-Bridgeman equation of state for mixtures although in the low temperature high pressure corner of the table the representation is somewhat better.

Van Lerberghe[32] has noticed that the generalized equation of state for a gas mixture:

$$p = f(T, V, n_1, n_2, \cdots) \tag{15}$$

in which V is the total volume and n_1, n_2, $\cdots$ the mole numbers of the Gases 1, 2, $\cdots$ in the mixture, can be developed into a Maclaurin series. This gives for a binary mixture the result:

$$p = p_1 + p_2 + \frac{n_1 n_2}{V^2}\omega_{12} \tag{16}$$

in which p_1 and p_2 are the pressures exerted by the Gases 1 and 2 respectively at the temperature T of the mixture and the molal concentrations n_1/V and n_2/V. The quantity ω_{12} is a function of the temperature and must be determined for each pair of substances. This relation represents the methane-nitrogen data well but it should be noted that in addition to data on the pure gases it is necessary to have available information concerning ω_{12} at each temperature, or the empirical temperature function for ω_{12} for each pair of gases. Thus new constants which cannot be calculated from those of the pure gases are introduced. This limits the usefulness of the method.

3. Previous Work on the Methods of Combination of the Constants.

Three methods of combining constants have been mentioned: linear, equation (7); linear square root, equation (8); and Lorentz, equation (10). For any given values of the constants for the pure gases, linear combination leads to the greatest value of the corresponding parameter for the mixture, linear square root to the smallest, and Lorentz combination to an intermediate value.

When an equation of state constant has the dimensions of volume, linear combination for the corresponding parameter for the mixture gives the simplest resulting equation; when the constant has the dimensions of volume squared, linear square root combination gives the simplest result; while the Lorentz method does not lead to simple equations in any case. In the first two cases mentioned the constants can be combined with the mole-numbers of the component gases instead of the mole fractions. Many of the uses to which an equation of state for gas mixtures is put require differentiation with respect to mole-numbers, and the resulting equations are simpler when mole-numbers can be used in the combination equations (7) or (8).

There have been three methods proposed for determining the interaction constant b_{12} and two for a_{12}, the Lorentz derivation not applying to this latter case. It is for experiment to determine:

(1) Which of these methods of combining constants gives the most satisfactory representation of the experimental compressibility data on gas mixtures.

(2) Which of these methods, if any, leads to an equation of state for gas mixtures that, when used to integrate the general equations for the thermodynamic properties of gas mixtures, gives relations which represent these properties satisfactorily.

(3) Which of the three methods: combination of the constants in

an equation of state, Dalton's law, Amagat's law gives the best results; and how much better is the preferred method.

The present paper deals with the first and last of these statements. There have been several investigations that have treated the question of what is the best method of combination for a given constant. We are concerned mainly with the a and b constants of van der Waals' equations or the corresponding constants A and β of the Keyes or A_0 and B_0 of the Beattie-Bridgeman equation. The methods of combination used for the higher order constants in the latter two equations of state are not so important since in general these constants do not have so great an effect on the calculation of the pressure.

In the evaluation of some of the thermodynamic properties of gas mixtures, the cohesive constant a has a relatively greater effect than any of the others. Eucken and Bresler[33] from their own measurements and those of Pollitzer and Strebel[34] on the effect of an indifferent gas on the vapor pressure of liquids calculated values of the interaction constant a_{12} by the use of certain expressions for the equilibrium pressures and the van der Waals equation of state. The b_{12} interaction constant was calculated by the Lorentz method, but it was remarked that the method of combination used for b did not greatly influence the result since the b constant does not enter markedly into the calculation. They found that the best representation of the interaction constant was given by linear square root combination for a.

Gillespie[35] investigated the limiting value of the expansion of a gas in a gas mixture as the pressure approaches zero at constant temperature and composition. The general relation for the intercept is:

$$\operatorname*{Limit}_{p \to 0} (\bar{v}_1 - v_1) = x_2^2 \left[\frac{A_{01} - 2A_{012} + A_{02}}{RT} - (B_{01} - 2B_{012} + B_{02}) \right] \quad (17)$$

where $\bar{v}_1$ is the partial molal volume of the Gas 1 in the mixture and v_1 the molal volume of Gas 1 in the pure state at the temperature and under the pressure of the mixture. The same expression results whether the van der Waals, Keyes, or Beattie-Bridgeman equation of state is used provided that in the latter two equations all of the higher order constants are combined according to the linear method. Since Gillespie actually used the values of the constants of the latter equation of state in his computations, it is written here in terms of these constants.

Twelve binary mixtures for which compressibility data existed in the literature were investigated by Gillespie; five for argon-ethylene mixtures, three for oxygen-ethylene, one for hydrogen-nitrogen, and three for nitrogen-methane. He found that the value of the intercept obtained by extrapolation of the values of $\bar{v}_1 - v_1$ determined from the experimental data to zero pressures is not zero as had been assumed by some writers but has in all of the cases studied a finite positive value.

When linear combination, equation (7), is used for B_0, the quantity $(B_{01} - 2\,B_{012} + B_{02})$ is zero [by equation (5)] and when either linear square root or Lorentz combination, equations (8) or (10) respectively, are used this quantity is positive since twice the interaction constant B_{012} determined by (6) or (9) is less than the sum of the constants for the pure gases. Thus linear combination for A_0 is excluded since in this case the contribution from the A_0 constant to the value of the intercept would be zero and the calculated intercept would be zero or negative. Moreover Gillespie showed that when linear square root combination was used for A_{0x} and either linear or Lorentz combination for B_{0x}, a good representation of the experimental intercepts was obtained. The argon-ethylene data pointed to the Lorentz method for B_{0x}, the oxygen-ethylene to the linear method, while the other two binary combinations did not strongly support either method but perhaps favored the linear method slightly. In no case was it impossible to exclude either method since the effect of B_0 on the calculation was smaller than that of the A_0 constant. On the other hand the linear square root combination for B_{0x} seems to be excluded since in all cases in which any doubt existed the values of intercepts obtained by extrapolation of the plots lay rather between those calculated by linear and Lorentz combination for B_0, whereas linear square root combination for B_{0x} would cause the calculated intercept to fall below the Lorentz value.

This investigation definitely indicates the linear square root combination for A_0 and either linear or Lorentz combination for B_0 with the linear method slightly favored.

4. THE EQUATION OF STATE FOR MIXTURES USED IN THE PRESENT COMPARISONS.

The virial form of the equation of state (12) when written for a gas mixture is:

$$p = \frac{R_n T}{V} + \frac{\beta_n}{V^2} + \frac{\gamma_n}{V^3} + \frac{\delta_n}{V^4} \tag{18}$$

$$\beta_n = R_n T B_{0n} - A_{0n} - R_n c_n / T^2$$
$$\gamma_n = - R_n T B_{0n} b_n + A_{0n} a_n - R_n B_{0n} c_n / T^2$$
$$\delta_n = R_n B_{0n} b_n c_n / T^2$$

where R_n, A_{0n}, a_n, B_{0n}, b_n and c_n are the values of the parameters for a mixture consisting of n_1, n_2, . . . moles of the Gases 1, 2, . . . respectively and V is the volume of Σn_i moles of the mixture. Any equation may be used for computing the values of the parameters from the constants of the pure gases and the composition; but a method that gave good results in the calculation of the pressures of nitrogen-methane mixtures[25] and of the expansion[35] of gases on mixing at low pressures is linear combination for each of the constants R, $A_0^{1/2}$, a, B_0, b and c, namely:

$$\begin{aligned} R_n &= n_1 R + n_2 R + \cdots &&= \Sigma(n_i)R \qquad (19) \\ A_{0n} &= (n_1 A_{01}^{1/2} + n_2 A_{02}^{1/2} + \cdots)^2 &&= (\Sigma n_i A_{0i}^{1/2})^2 \\ a_n &= n_1 a_1 + n_2 a_2 + \cdots &&= \Sigma(n_i a_i) \\ B_{0n} &= n_1 B_{01} + n_2 B_{02} + \cdots &&= \Sigma(n_i B_{0i}) \\ b_n &= n_1 b_1 + n_2 b_2 + \cdots &&= \Sigma(n_i b_i) \\ c_n &= n_1 c_1 + n_2 c_2 + \cdots &&= \Sigma(n_i c_i) \end{aligned}$$

In these relations n_1, n_2, $\cdots$ may represent: (1) the number of moles of the component gases, in which case the volume V used in (18) is the total volume of Σn_i moles; (2) the mole fraction of the component gases, the volume v being the volume of an average mole of mixture, that is $V/\Sigma n_i$; (3) the weight fractions of the component gases, the volume v referring to one gram of mixture. In the latter case R has a different value for each gas and $R_n = \Sigma(n_i R_i)$.

The method of combination (19) not only gives a satisfactory representation of the experimental data in the several cases in which it has been used, but leads to relatively simple equations for the thermodynamic properties of gas mixtures. Provisionally, we may consider that the method of combination is settled for all of the constants except for B_0 which, in addition to the method shown in (19), may also be combined either by the Lorentz or the linear square root method. In the former case all of the equations of (19) remain the same except that for B_{0n} which becomes:

$$B_{0x} = x_1^2 B_{01} + \tfrac{1}{4} x_1 x_2 (B_{01}^{1/3} + B_{02}^{1/3})^3 + x_2^2 B_{02} \qquad (20)$$

and in the latter case it is necessary to replace the relation for B_{0_n} of (19) by:

$$B_{0_x} = (\Sigma x_i B_{0_i}{}^{1/2})^2 \tag{21}$$

In (20) and (21) only the mole fraction may be used since the quantity B_0 has the dimensions of volume. For the calculation of the pressures of a gaseous mixture, the use of either of these methods of combination does not introduce serious difficulties; but either expression leads to rather involved relations for some of the thermodynamic properties of gas mixtures, especially those requiring differentiation with respect to the composition.

5. THE EXPERIMENTAL DATA.

The earlier work[26] on the compressibility of gaseous mixtures was rather fragmentary. Recently, however, there have been several investigations that extend to moderately high pressures:

1. Kuenen, Verschoyle and van Urk[37] measured the compressibility of two mixtures of oxygen and nitrogen. These data are not treated in the present paper since they are for the most part in the critical region and also because the values of the equation of state constants for oxygen and nitrogen are so similar that the comparison would have very little bearing on the mixture equation of state.

2. Masson and Dolley[17] measured the compressibility of five mixtures of argon with ethylene, three mixtures of oxygen with ethylene, one of argon with oxygen, and of the three pure gases at 24.95° C. and to 125 atmospheres. The gas compositions were expressed as percentages by volume of the separate components each taken at 24.95° C. and 1 atmosphere. The volumes of each mixture were given in terms of the sum of the volumes of the component gases each measured at 24.95° C. and 1 atmosphere.

3. Verschoyle[38] determined the compressibility of three mixtures of hydrogen and nitrogen and of the two pure gases at 0° and 20° C. to 200 atmospheres. The meaning of the term "percentage composition" was not stated, so that it was assumed that this expression denoted percentages by volume of the separate components each taken at 20° C. For each mixture the unit of volume was the volume of that mixture at 0° C. and 1 atmosphere.

4. Keyes and Burks[16, 28] studied the compressibility of three mixtures of nitrogen and methane and of methane from 0° to 200° C. and to about 300 atmospheres. Smith and Taylor[27] using the same apparatus had previously studied the compressibility of pure nitrogen.

The composition of the mixtures were given in percentages by weight, and volumes in ccm. per gram.

5. Bartlett, Cupples and Tremearne[39] determined the compressibility of one mixture of hydrogen and nitrogen and of the pure gases from 0° to 400° C. and to 1000 atmospheres. These data are not treated in the present paper.

6. Gibby, Tanner and Masson[40] studied the compressibility of one mixture of helium and hydrogen and of the pure gases from 25 to 175° C. and of several mixtures at 25° C. The original data are not given, but they list the parameters a and b of the relation:

$$pv = a + bp$$

for each isotherm of each mixture. The curve obtained by plotting the values of b against the composition of the corresponding mixture for 25° C. exhibits a maximum of about 80% hydrogen. Thus some mixtures of hydrogen and helium are less compressible than either of the pure gases.

7. Scott[41] measured the compressibility of three mixtures of hydrogen and carbon monoxide and of the pure gases at 25° C. and to 170 atmospheres. The meaning of "percentage composition" is not given but it is stated that the compositions were determined by chemical analyses. This may mean that the compositions are percentages by volume at some low pressure or true molal percentages. In our treatment of these data it was assumed that compositions were expressed in mole percent, the difference between the two methods of giving compositions being probably within the experimental error of the measurements. Volumes were given in terms of the volumes of the mixtures at 25° C. and 1 atmosphere each of which was assumed to have the value 1.09155 under these conditions.

In all of the measurements mentioned above temperatures were expressed in degrees centigrade and it is assumed that pressures were in normal atmospheres.

In Table I is given a résumé of the methods of expressing compositions used by the four groups of investigators whose data are treated in the present paper, together with the corresponding mole fractions. The values of the molal volumes of the pure gases used for the data of Masson and Dolley and of Verschoyle were computed from the equation of state.

6. TREATMENT OF THE EXPERIMENTAL DATA.

The values of the constants of the Beattie-Bridgeman equation of state for several gases have been published[26, 35] in units of atmospheres, liters per mole and degrees Kelvin. In Table II are given a résumé of the volume units in which the data of the four groups of observers are expressed and the conversion factor by which the density in moles per liter must be multiplied to reduce it to the units in which the data are given.

In order to calculate the value of the conversion factor for Masson and Dolley's measurements it is required to know the molal volumes of the pure gases at 24.95° C. and 1 atmosphere, and these values were computed from the equation of state for these gases.

For the measurements of Verschoyle and of Scott it is necessary to know the molal volumes of the mixtures at 20° C and 1 atmosphere. and at 25° C. and 1 atmosphere respectively. These values were computed from the equation of state for mixtures. It is evident that this computed value depends on the method of combination of constants used. Hence in each case one factor was calculated using the linear method of equation (19), and one factor using the method of (19) for all constants except B_{0x} for which the Lorentz method (20) was used. The first factor was employed whenever linear combination for B_{0x} was used as in Table IV and the second when Lorentz combination was used, Table V.

The measurements of Keyes and Burks were expressed in volume units of ccm. per gram, and the calculations were made in the same units.

In Table III are given the values of the equation of state constants for the pure gases and of the parameters for the mixtures calculated according to the relations (19). There is also given in each case the value of B_{0x} obtained by using Lorentz combination, equation (20). For the data of Keyes and Burks the weight fractions and the values of the constants in units of ccm. per gram were substituted into (19). In the Lorentz combination of B_0 for the latter data however the calculation was carried out using mole fractions and the values of B_0 for the pure gases in ccm. per mole. The value of B_{0x} so obtained was divided by the average molecular weight of the mixture given in Table I to obtain the value of B_{0w} which can be used when volumes are in ccm. per gram.

In Table IV are given the values of the virial coefficients β_n, γ_n and δ_n of equation (18) for each of the pure gases and mixtures at

TABLE I.

CALCULATION OF THE COMPOSITIONS IN MOLE FRACTIONS.

1. *Data of Masson and Dolley.*

Compositions expressed as percentages by volume of the separate constituents each taken at 24.95°C. and 1 atm.

Gas	Argon	Oxygen	Ethylene
Molal volume at 24.95°, 1 atm. (liters)	24.4448	24.4440	24.3214

Volume percent		Mole fraction	
A	C_2H_4	A	C_2H_4
75.26	24.74	0.7517	0.2483
50.05	49.95	.4992	.5008
40.14	59.86	.4002	.5998
29.28	70.72	.2918	.7082
9.94	90.06	.0989	.9011

Volume percent		Mole fraction	
O_2	C_2H_4	O_2	C_2H_4
74.73	25.27	0.7463	0.2537
50.09	49.91	.4996	.5004
40.16	59.84	.4004	.5996

Volume percent		Mole fraction	
A	O_2	A	O_2
49.99	50.01	0.4999	0.5001

2. *Data of Verschoyle.*

Compositions expressed as percentages by volume of the separate constituents each taken at 20°C. and 1 atm.

Gas	Hydrogen	Nitrogen
Molal volume at 20°, 1 atm. (liters)	24.0670	24.0472

Volume percent		Mole fraction	
H_2	N_2	H_2	N_2
75.00	25.00	0.7498	0.2502
50.00	50.00	.4998	.5002
25.00	75.00	.2498	.7502

TABLE I—Concluded.

3. *Data of Keyes and Burks.*

Compositions expressed as percentages by weight.

Gas	Nitrogen	Methane
Molecular Weight	28.016	16.0308

Weight percent		Mole fraction		Average mol. wt.
N_2	CH_4	N_2	CH_4	
69.556	30.444	0.5666	0.4334	22.8216
31.014	68.986	.2046	.7954	18.4831
29.69	70.31	.1946	.8054	18.3632

4. *Data of Scott.*

Compositions expressed as molal percentages (determined by chemical analyses).

Mole percent		Mole fraction	
H_2	CO	H_2	CO
66.3	33.7	0.663	0.337
51.7	48.3	.517	.483
33.1	66.9	.331	.669

each of the temperatures for which compressibility data exist. The values of the parameters for the mixtures are those obtained by use of the method of combination (19) and appear in Table III. The virial coefficients are given first in units of atmospheres, liters per mole and degrees Kelvin and then in the volume units of the data. The conversion was made by dividing RT, β_n, γ_n and δ_n by the appropriate factor given in Table II raised to the first, second, third and fourth powers respectively.

In Table V the values of the virial coefficients are given when the method of combination (19) is used for all constants except B_0 which is combined by the Lorentz method (20). The conversion factors used in this case for the data of Verschoyle and Scott are those listed in Table II under the heading "Lorentz B_{0x}."

The virial coefficients were not computed for the data of Keyes and Burks since their measurements were made by the isometric method. The calculated values were computed accordingly, as described in an earlier paper.[25]

It is to be noted that there are no measurements of the compressibility of carbon monoxide that extend over a sufficiently wide temperature and pressure range to permit the determination of the equation of state constants for this gas. Computations[42] of the weight of a normal liter of carbon monoxide by use of the constants for nitrogen have confirmed the conclusion drawn from Langmuir's[43] theory of isosters that the constants for carbon monoxide should not differ greatly from those for nitrogen. Accordingly, in the present comparison the constants for nitrogen were used for carbon monoxide and this procedure is justified by the fact that to 170 atmospheres the deviation between the calculated and observed pressures for carbon monoxide are of the same order of magnitude as those for hydrogen (see Figure 21).

A value of the pressure was calculated from the virial coefficients given in Table IV, and one from the values given in Table V for each observed point of Masson and Dolley, Verschoyle, and Scott. Corresponding computations were made with the aid of the values given in Table III for the results of Keyes and Burks. The percentage deviations of the calculated from the observed pressures:

$$\% = 100\,\frac{\text{obs. pressure} - \text{calcd. pressure}}{\text{obs. pressure}}$$

were plotted against the observed pressures for each case. The plots are given in Figures 1 to 24. Figures 1, 10, 14 and 21 exhibit the results for the pure gases. For each mixture there are two curves: one, marked "Lin," representing the deviations when the method of combination (19) is used for all constants; and, the other, marked "Lor," giving the deviation when the relations (19) are used for all of the constants except B_0 which is combined according to the Lorentz method (20). On each mixture plot for the data of Masson and Dolley, Verschoyle, and Scott there also appears a curve, marked "Sum," the ordinate of which at a given pressure is the sum $(x_1\%_{C1} + x_2\%_{C2})$ where x_1 and x_2 refer to the mole fraction of the Gases 1 and 2 in the mixture, and $\%_{C1}$ and $\%_{C2}$ to the percentage deviations (from Figure 1, 10, 14 or 21) for the pure gases at that pressure.

Although in some cases there were slight irregularities, smooth curves were drawn except for the data of Verschoyle. No curves are given for the argon-oxygen mixture since the three curves "Lin," "Lor," and "Sum" practically coincide when plotted on the same scale as that used for the other figures.

TABLE II.

Calculation of the Volume Conversion Factors.

$$\text{Conversion factor} = \frac{\text{Volume in liters per mole.}}{\text{Volume in units of experimental data.}}$$

1. *Data of Masson and Dolley.*

$$\text{Volume (M and D)} = \frac{\text{Volume of mixture at 24.95° C. and } p \text{ atm.}}{\text{Sum of volumes of separate constituents each taken at 24.95° C. and 1 atm.}}$$

Factor = $\Sigma(x_i V_i)$; V_1 = molal volume in liters of Gas 1 at 24.95° C. and 1 atm.

Mole fraction		Factor
A	C_2H_4	
1.0000	0.0000	24.4448
0.7517	0.2483	24.4142
0.4992	0.5008	24.3830
0.4002	0.5998	24.3708
0.2918	0.7082	24.3574
0.0989	0.9011	24.3336
0.0000	1.0000	24.3214

Mole fraction		Factor
O_2	C_2H_4	
1.0000	0.0000	24.4440
0.7463	0.2537	24.4129
0.4996	0.5004	24.3827
0.4004	0.5996	24.3705
0.0000	1.0000	24.3214

Mole fraction		Factor
A	O_2	
1.0000	0.0000	24.4448
0.4999	0.5001	24.4444
0.0000	1.0000	24.4440

TABLE II.—Concluded.

2. *Data of Verschoyle.*

$$\text{Volume (Verschoyle)} = \frac{\text{Volume of mixture at } t^\circ \text{ C. and } p \text{ atm.}}{\text{Volume of mixture at } 0^\circ \text{ C. and 1 atm.}}$$

Factor = molal volume in liters of mixture at 0° C. and 1 atm.

Mole fraction		Factor	Factor
H_2	N_2	Linear B_{0x}	Lorentz B_{0x}
1.0000	0.0000	22.425204	
0.7498	0.2502	22.423559	22.422760
0.4998	0.5002	22.419065	22.418000
0.2498	0.7502	22.411722	22.410924
0.0000	1.0000	22.401534	

3. *Data of Keyes and Burks.*

Volume (K and B) = Specific volume in cubic centimeters per gram.
Calculations carried out in same volume units.

4. *Data of Scott.*

$$\text{Volume (Scott)} = \frac{\text{Volume of mixture at } 25^\circ \text{ C. and } p \text{ atm.}}{\text{Volume of mixture at } 25^\circ \text{ C. and 1 atm.}} \times 1.09155.$$

$$\text{Factor} = \frac{V}{1.09155}; \ V = \text{molal volume in liters of mixture at } 25^\circ \text{ C. and 1 atm.}$$

Mole fraction		V	Factor	V	Factor
H_2	CO	Linear B_{0x}		Lorentz B_0	
1.000	0.000	24.477445	22.424484		
0.663	0.337	24.475739	22.422921	24.474786	22.422048
0.517	0.483	24.473527	22.420894	24.472462	22.419918
0.331	0.669	24.469419	22.417131	24.468475	22.416266
0.000	1.000	24.458534	22.407159		

TABLE III.

VALUES OF THE PARAMETERS IN THE BEATTIE-BRIDGEMAN EQUATION OF STATE.

Equation of state given in equation (12); virial form in equation (18).

Method of combination of constants given in equations (19); Lorentz method for B_{0x} in (20).

Units: normal atmospheres, liters per mole, degrees Kelvin (T°K = t° C + 273.13); except for Keyes and Burks' data for which volumes are in ccm. per gram.

1. *Data of Masson and Dolley.*

Mole fraction		$\Sigma(x_i)R$	$(\Sigma x_i A_{0i}^{1/2})^2$	$\Sigma(x_i a_i)$	$\Sigma(x_i B_{0i})$	$\Sigma(x_i b_i)$	$\Sigma(x_i c_i)\times 10^{-4}$	Lorentz B_{0x}
A	C_2H_4							
1.0000	0.0000	0.08206	1.2907	0.02328	0.03931	0.0	5.99	
0.7517	0.2483	0.08206	2.16050	0.029825	0.059733	0.008931	10.134	0.056910
0.4992	0.5008	0.08206	3.27350	0.036481	0.080501	0.018014	14.348	0.076720
0.4002	0.5998	0.08206	3.77276	0.039091	0.088644	0.021575	16.001	0.085014
0.2918	0.7082	0.08206	4.36006	0.041948	0.097559	0.025474	17.810	0.094435
0.0989	0.9011	0.08206	5.51018	0.047033	0.113425	0.032413	21.029	0.112078
0.0000	1.0000	0.08206	6.1520	0.04964	0.12156	0.03597	22.68	
O_2	C_2H_4							
1.0000	0.0000	0.08206	1.4911	0.02562	0.04624	0.004208	4.80	
0.7463	0.2537	0.08206	2.37335	0.031714	0.065349	0.012266	9.336	0.063090
0.4996	0.5004	0.08206	3.42701	0.037640	0.083930	0.020102	13.747	0.080948
0.4004	0.5996	0.08206	3.90510	0.040022	0.091402	0.023252	15.521	0.088538
A	O_2							
0.4999	0.5001	0.08206	1.38911	0.024450	0.042776	0.002104	5.395	0.042729

TABLE III.—Concluded.

2. *Data of Verschoyle.*

Mole fraction		$(\Sigma x_i)R$	$(\Sigma x_i A_{0i}^{1/2})^2$	$\Sigma(x_i a_i)$	$\Sigma(x_i B_{0i})$	$\Sigma(x_i b_i)$	$\Sigma(x_i c_i)\times 10^{-4}$	Lorentz B_{0x}
H_2	N_2							
1.0000	0.0000	0.08206	0.1975	−0.00506	0.02096	−0.04359	0.0504	
0.7498	0.2502	0.08206	0.38854	+0.002754	0.028341	−0.034413	1.08863	0.027542
0.4998	0.5002	0.08206	0.64338	+0.010561	0.035716	−0.025243	2.12603	0.034651
0.2498	0.7502	0.08206	0.96214	+0.018369	0.043091	−0.016073	3.16343	0.042293
0.0000	1.0000	0.08206	1.3445	+0.02617	0.05046	−0.00691	4.20	

3. *Data of Keyes and Burks.*

Weight fraction		$\Sigma(w_i R_i)$	$(\Sigma w_i A_{0i}^{1/2})^2$	$\Sigma(w_i a_i)$	$\Sigma(w_i B_{0i})$	$\Sigma(w_i b_i)$	$\Sigma(w_i c_i)\times 10^{-6}$	Lorentz B_{0w}
N_2	CH_4							
1.0000	0.0000	2.92904	1457.5	0.6382	1.5398	−0.5740	2.00	
0.69556	0.30444	3.59572	3048.2	0.7961	2.1321	−0.7006	3.827	2.1262
0.31014	0.68986	4.43974	5894.4	0.9961	2.8819	−0.8610	6.139	2.8770
0.2969	0.7031	4.46873	6008.7	1.0030	2.9076	−0.8665	6.219	2.9029
0.0000	1.0000	5.11890	8860.0	1.1570	3.4852	−0.9900	8.00	

4. *Data of Scott.*

Mole fraction		$\Sigma(x_i)R$	$(\Sigma x_i A_{0i}^{1/2})^2$	$\Sigma(x_i a_i)$	$\Sigma(x_i B_{0i})$	$\Sigma(x_i b_i)$	$\Sigma(x_i c_i)\times 10^{-4}$	Lorentz B_{0x}
H_2	CO							
1.000	0.000	0.08206	0.1975	−0.00506	0.02096	−0.04359	0.0504	
0.663	0.337	0.08206	0.46978	+0.005465	0.030902	−0.031229	1.44882	0.029950
0.517	0.483	0.08206	0.62380	+0.010024	0.035209	−0.025874	2.05466	0.034145
0.331	0.669	0.08206	0.85160	+0.015833	0.040696	−0.019051	2.82648	0.039752
0.000	1.000	0.08206	1.3445	+0.02617	0.05046	−0.00691	4.20	

TABLE IV.

VALUES OF THE VIRIAL COEFFICIENTS.

Linear combination of *R*, $A_0^{1/2}$, *a*, B_0, *b* and *c*.

Virial coefficients calculated by use of the relations (18) from the values given in Table III.

"Normal units" are normal atmospheres, liters per mole, degrees Kelvin.

"Units of data" are normal atmospheres, volume units in which experimental data are expressed (see Table II), degrees Kelvin.

1. *Data of Masson and Dolley.*

$t = 24.95°$ C.

Mole fraction		Virial coefficients in normal units				Virial coefficients in units of data			
A	C_2H_4	*RT*	β_n	$\gamma_n \times 10^2$	$\delta_n \times 10^4$	*RT*	$\beta_n \times 10^3$	$\gamma_n \times 10^6$	$\delta_n \times 10^9$
1.0000	0.0000	24.460445	−0.3844812	2.787282	0.0	1.000640	−0.64343	1.9082	0.0
0.7517	0.2483	24.460445	−0.7929980	4.579723	0.49930	1.001894	−1.33041	3.1471	0.141
0.4992	0.5008	24.460445	−1.4369223	7.328196	1.92162	1.003176	−2.41690	5.0552	0.544
0.4002	0.5998	24.460445	−1.7522674	8.760077	2.82627	1.003678	−2.95026	6.0520	0.801
0.2918	0.7082	24.460445	−2.1382098	10.605914	4.08784	1.004231	−3.60403	7.3393	1.161
0.0989	0.9011	24.460445	−2.9299698	14.720391	7.14023	1.005213	−4.94824	10.2165	2.037
0.0000	1.0000	24.460445	−3.3880521	17.296925	9.15883	1.005717	−5.72760	12.0227	2.617
O_2	C_2H_4								
1.0000	0.0000	24.460445	−0.4043800	3.139266	0.08626	1.000673	−0.67678	2.1494	0.024
0.7463	0.2537	24.460445	−0.8611081	5.002701	0.69114	1.001948	−1.44484	3.4383	0.195
0.4996	0.5004	24.460445	−1.5010069	7.706803	2.14205	1.003189	−2.52475	5.3165	0.606
0.4004	0.5996	24.460445	−1.8127124	9.120253	3.04650	1.003691	−3.05211	6.3011	0.864
A	O_2								
0.4999	0.5001	24.460445	−0.3926161	2.963092	0.04484	1.000656	−0.65707	2.0286	0.013

TABLE IV.—Concluded.

2. *Data of Verschoyle.*

t = 20° C.

Mole fraction		Virial coefficients in normal units				Virial coefficients in units of data			
H_2	N_2	RT	β_n	$\gamma_n \times 10^2$	$\delta_n \times 10^4$	RT	$\beta_n \times 10^3$	$\gamma_n \times 10^6$	$\delta_n \times 10^9$
1.0000	0.0000	24.054248	0.3061957	2.096764	−0.00440	1.072643	0.60887	1.8593	−0.002
0.7498	0.2502	24.054248	0.2827848	2.423547	−0.10140	1.072722	0.56240	2.1495	−0.040
0.4998	0.5002	24.054248	0.1954376	2.775637	−0.18306	1.072937	0.38884	2.4633	−0.072
0.2498	0.7502	24.054248	0.0441703	3.303173	−0.20924	1.073289	0.08794	2.9343	−0.083
0.0000	1.0000	24.054248	−0.1708334	4.154878	−0.13986	1.073777	−0.34042	3.6959	−0.056

t = 0° C.

H_2	N_2								
1.0000	0.0000	22.413048	0.2717231	1.946663	−0.00507	0.999458	0.54032	1.7262	−0.002
0.7498	0.2502	22.413048	0.2346933	2.259008	−0.11679	0.999531	0.46676	2.0036	−0.046
0.4998	0.5002	22.413048	0.1337381	2.616660	−0.21085	0.999732	0.26608	2.3222	−0.083
0.2498	0.7502	22.413048	−0.0311371	3.169740	−0.24101	1.000059	−0.06199	2.8158	−0.096
0.0000	1.0000	22.413048	−0.2597376	4.066926	−0.16109	1.000514	−0.51758	3.6177	−0.064

3. *Data of Scott.*

t = 25° C.

H_2	CO								
1.000	0.000	24.464548	0.3148116	2.134284	−0.00425	1.090975	0.62605	1.8927	−0.002
0.663	0.337	24.464548	0.2728472	2.576323	−0.12909	1.091051	0.54267	2.2852	−0.051
0.517	0.483	24.464548	0.2186026	2.787221	−0.17281	1.091150	0.43486	2.4729	−0.068
0.331	0.669	24.464548	0.1179137	3.138875	−0.20232	1.091333	0.23464	2.7863	−0.080
0.000	1.000	24.464548	−0.1487955	4.175916	−0.13521	1.091818	−0.29636	3.7119	−0.054

TABLE V.

VALUES OF THE VIRIAL COEFFICIENTS.

Linear combination of R, $A_0^{1/2}$, a, b, c and Lorentz combination of B_0.

1. *Data of Masson and Dolley.*

$t = 24.95°$ C.

Mole fraction		Virial coefficients in normal units				Virial coefficients in units of data			
A	C_2H_4	RT	β_n	$\gamma_n \times 10^2$	$\delta_n \times 10^4$	RT	$\beta_n \times 10^3$	$\gamma_n \times 10^6$	$\delta_n \times 10^9$
0.7517	0.2483	24.460445	−0.8620498	4.667815	0.47570	1.001894	−1.44626	3.2076	0.134
0.4992	0.5008	24.460445	−1.5294073	7.544902	1.83137	1.003176	−2.57246	5.2047	0.518
0.4002	0.5998	24.460445	−1.8410588	9.005288	2.71053	1.003678	−3.09976	6.2214	0.768
0.2918	0.7082	24.460445	−2.2146242	10.851958	3.95694	1.004231	−3.73283	7.5096	1.124
0.0989	0.9011	24.460445	−2.9629179	14.853347	7.05544	1.005213	−5.00388	10.3087	2.012
O_2	C_2H_4								
0.7463	0.2537	24.460445	−0.9163642	5.089956	0.66725	1.001948	−1.53755	3.4983	0.188
0.4996	0.5004	24.460445	−1.5739479	7.891289	2.06594	1.003189	−2.64744	5.4438	0.585
0.4004	0.5996	24.460445	−1.8827671	9.324198	2.95104	1.003691	−3.17006	6.4420	0.837
A	O_2								
0.4999	0.5001	24.460445	−0.3937658	2.963568	0.04479	1.000656	−0.65899	2.0290	0.013

TABLE V.—Concluded.

2. *Data of Verschoyle.*

$t = 20°$ C.

Mole fraction		Virial coefficients in normal units				Virial coefficients in units of data			
H_2	N_2	RT	β_n	$\gamma_n \times 10^2$	$\delta_n \times 10^4$	RT	$\beta_n \times 10^3$	$\gamma_n \times 10^6$	$\delta_n \times 10^9$
0.7498	0.2502	24.054248	0.2635655	2.358238	−0.09854	1.072760	0.52422	2.0918	−0.039
0.4998	0.5002	24.054248	0.1698198	2.713132	−0.17760	1.072988	0.33791	2.4081	−0.070
0.2498	0.7502	24.054248	0.0249750	3.274731	−0.20537	1.073327	0.04973	2.9094	−0.081

$t = 0°$ C.

H_2	N_2								
0.7498	0.2502	22.413048	0.2167852	2.198338	−0.11350	0.999567	0.43117	1.9500	−0.045
0.4998	0.5002	22.413048	0.1098682	2.558896	−0.20456	0.999779	0.21861	2.2712	−0.081
0.2498	0.7502	22.413048	−0.0490227	3.143769	−0.23655	1.000095	−0.09760	2.7930	−0.094

3. *Data of Scott.*

$t = 25°$ C.

H_2	CO								
0.663	0.337	24.464548	0.2495570	2.504863	−0.12511	1.091093	0.49639	2.2221	−0.049
0.517	0.483	24.464548	0.1925723	2.721889	−0.16759	1.091197	0.38311	2.4153	−0.066
0.331	0.669	24.464548	0.0948192	3.097341	−0.19763	1.091375	0.18870	2.7498	−0.078

7. GRAPHS OF THE DEVIATIONS OF THE PRESSURES CALCULATED BY THE BEATTIE-BRIDGEMAN EQUATION OF STATE FOR MIXTURES FROM THE OBSERVED VALUES.

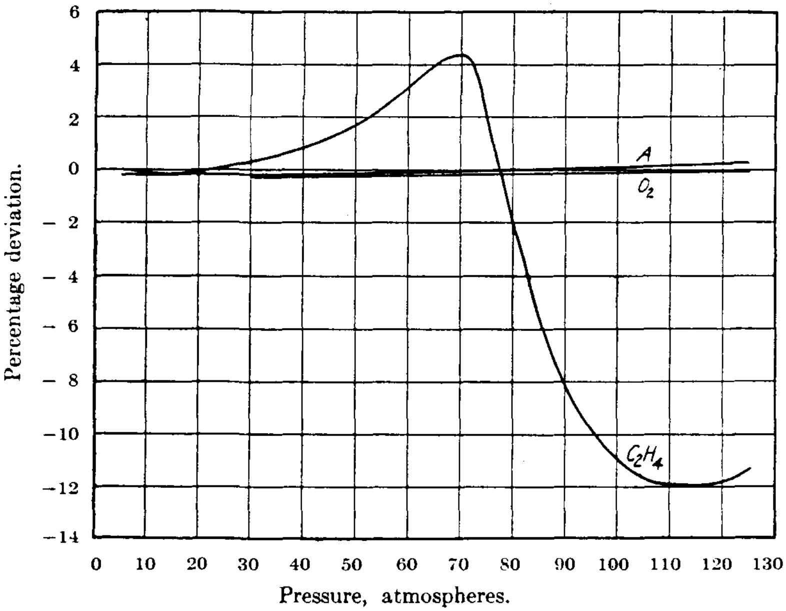

FIGURE 1. Masson and Dolley: Argon, oxygen and ethylene at 24.95° C.

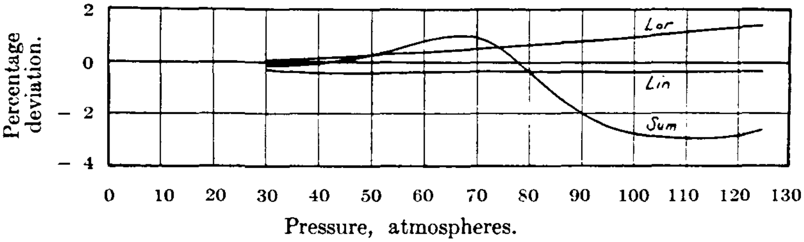

FIGURE 2. Masson and Dolley: 75.17% argon, 24.83% ethylene at 24.95° C.

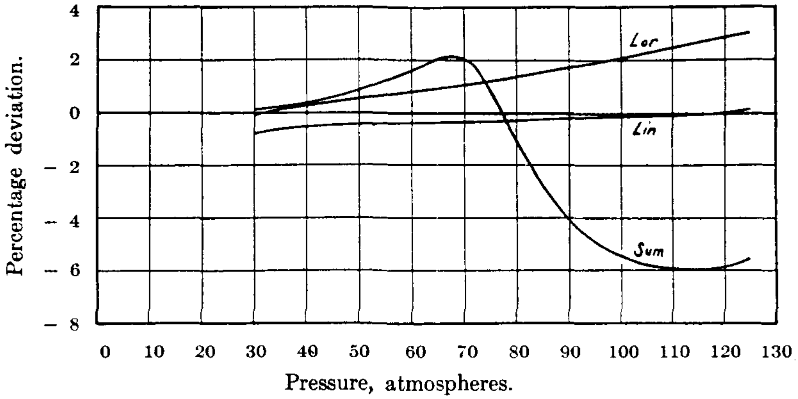

FIGURE 3. Masson and Dolley: 49.92% argon, 50.08% ethylene at 24.95° C.

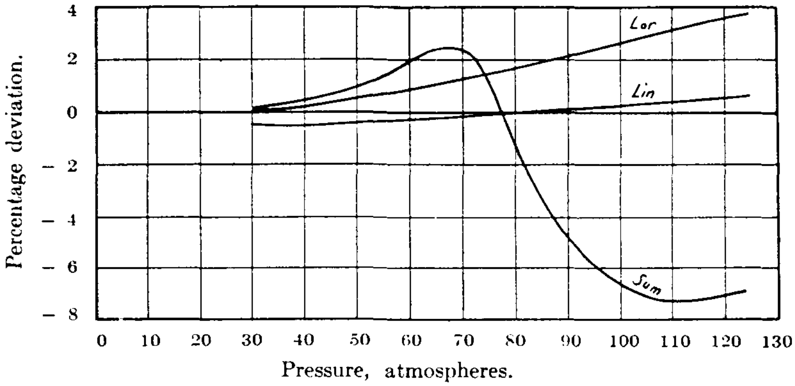

FIGURE 4. Masson and Dolley: 40.02% argon, 59.98% ethylene at 24.95° C.

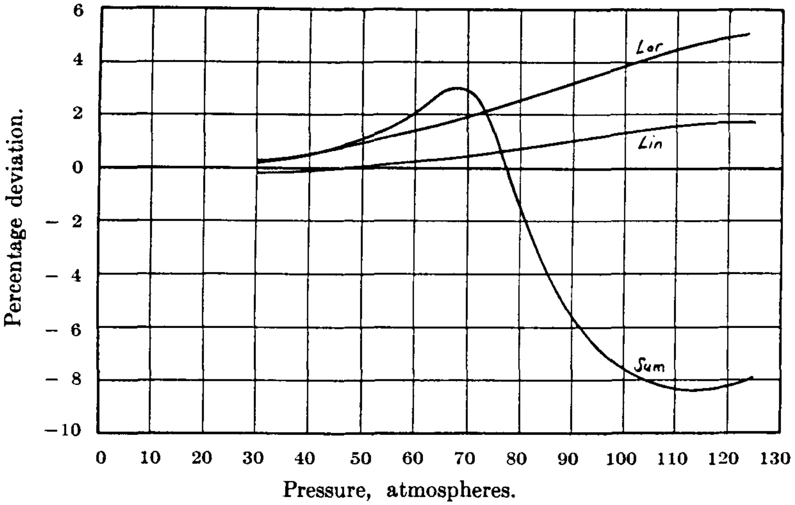

FIGURE 5. Masson and Dolley: 29.18% argon, 70.82% ethylene at 24.95° C.

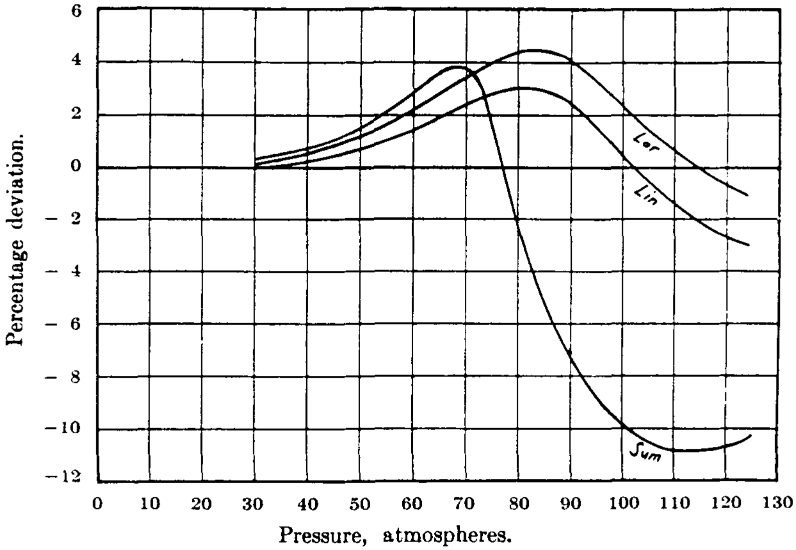

FIGURE 6. Masson and Dolley: 9.89% argon, 90.11% ethylene at 24.95° C.

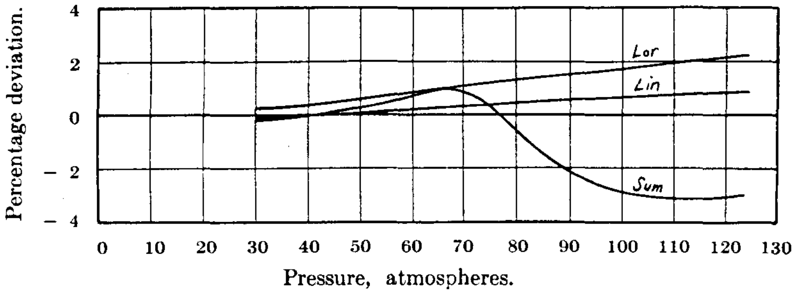

FIGURE 7. Masson and Dolley: 74.63% oxygen, 25.37% ethylene at 24.95°C.

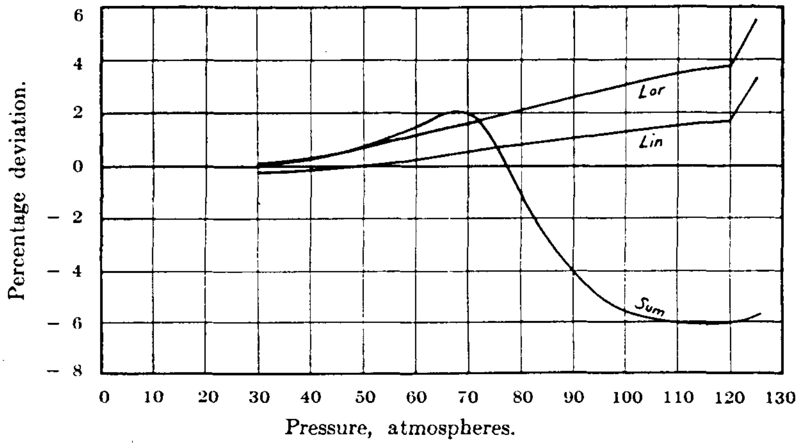

FIGURE 8. Masson and Dolley: 49.96% oxygen, 50.04% ethylene at 24.95° C.

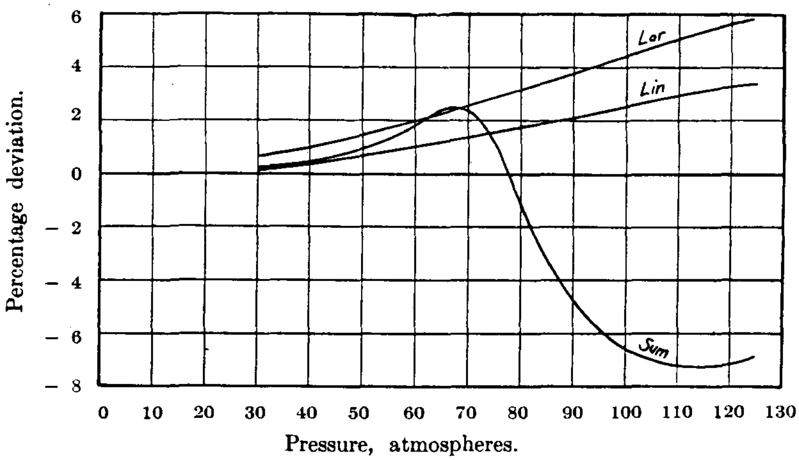

FIGURE 9. Masson and Dolley: 40.04% oxygen, 59.96% ethylene at 24.95° C.

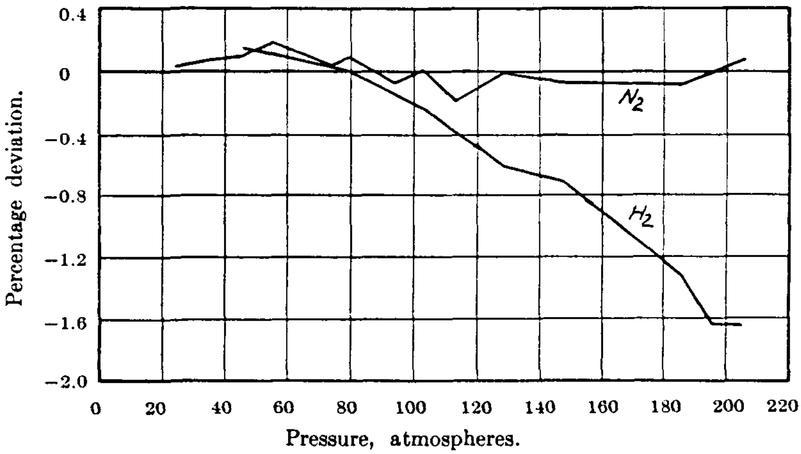

FIGURE 10. Verschoyle: Hydrogen and nitrogen at 20° C.

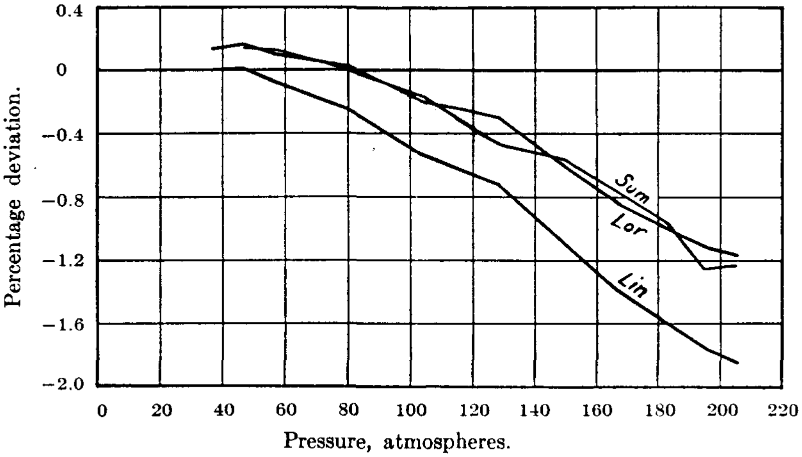

FIGURE 11. Verschoyle: 74.98% hydrogen, 25.02% nitrogen at 20° C.

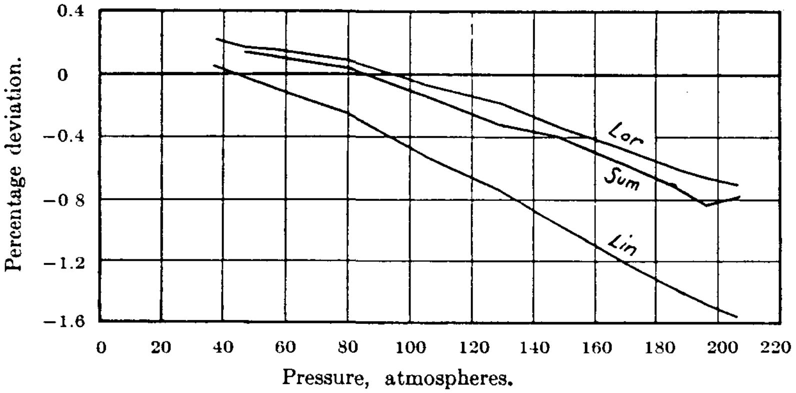

FIGURE 12. Verschoyle: 49.98% hydrogen, 50.02% nitrogen at 20° C.

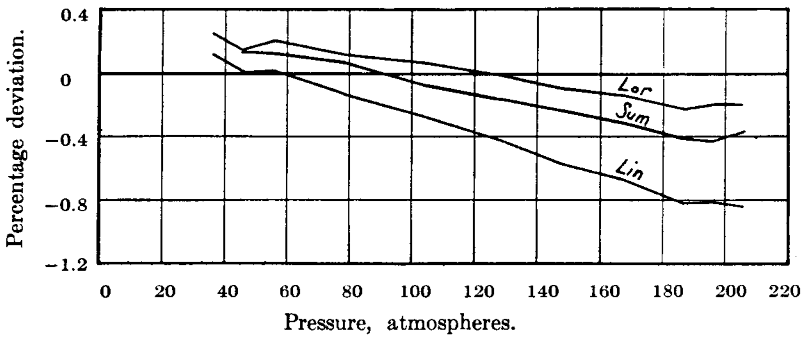

FIGURE 13. Verschoyle: 24.98% hydrogen, 75.02% nitrogen at 20° C.

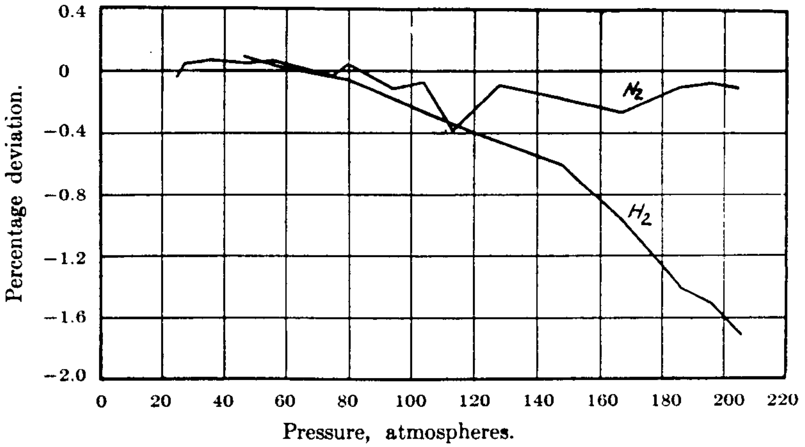

FIGURE 14. Verschoyle: Hydrogen and nitrogen at 0° C.

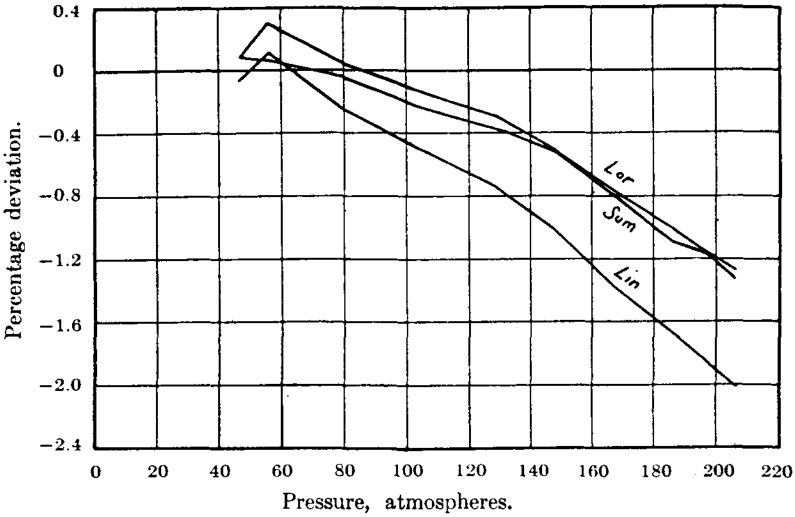

FIGURE 15. Verschoyle: 74.98% hydrogen, 25.02% nitrogen at 0° C.

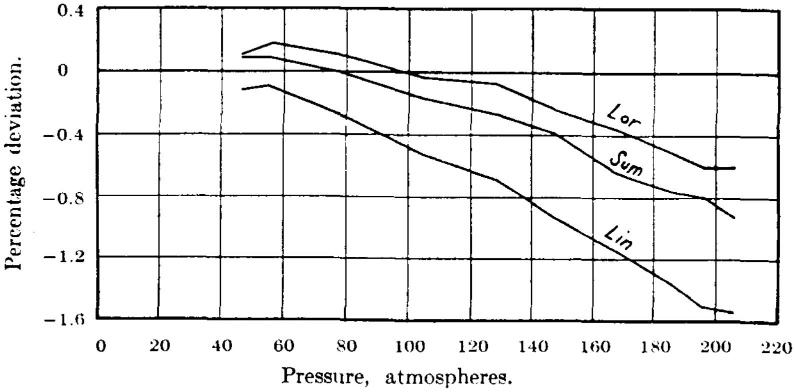

FIGURE 16. Verschoyle: 49.98% hydrogen, 50.02% nitrogen at 0° C.

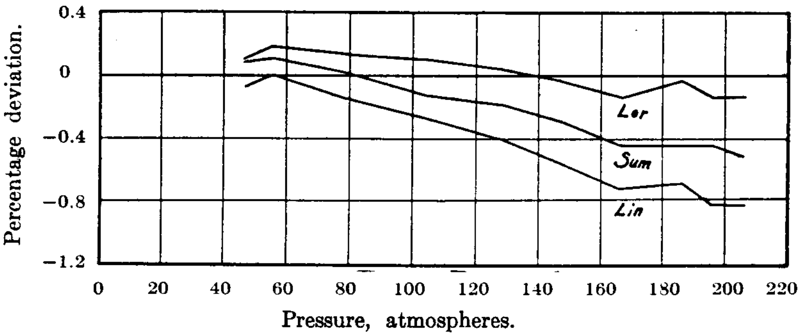

Figure 17. Verschoyle: 24.98% hydrogen, 75.02% nitrogen at 0° C.

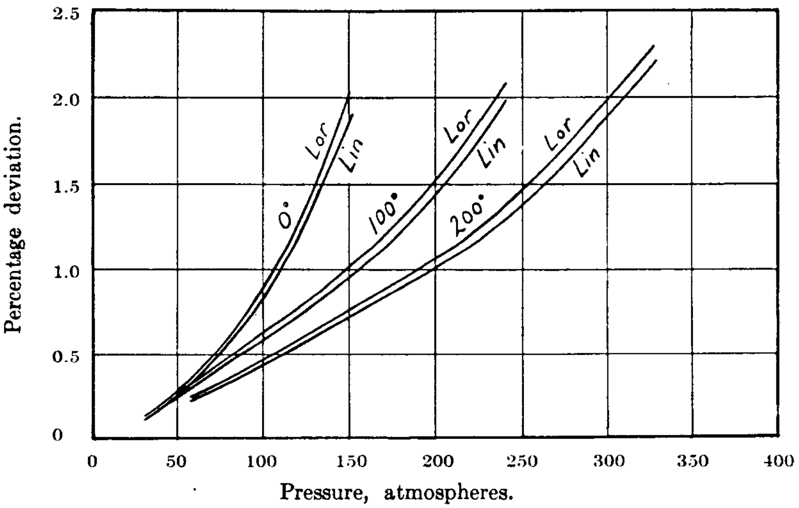

Figure 18. Keyes and Burks: 56.66% nitrogen, 43.34% methane at 0°, 100° and 200° C.

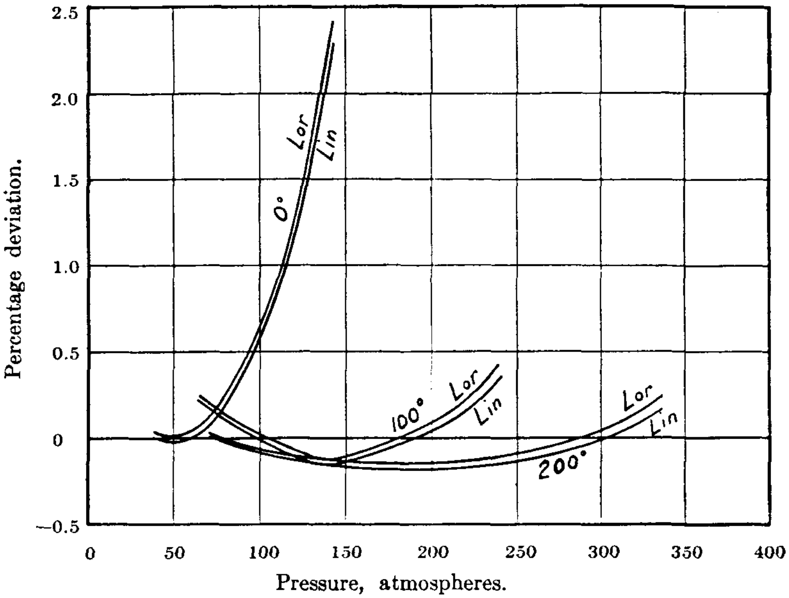

FIGURE 19. Keyes and Burks: 20.46% nitrogen, 79.54% methane at 0°, 100° and 200° C.

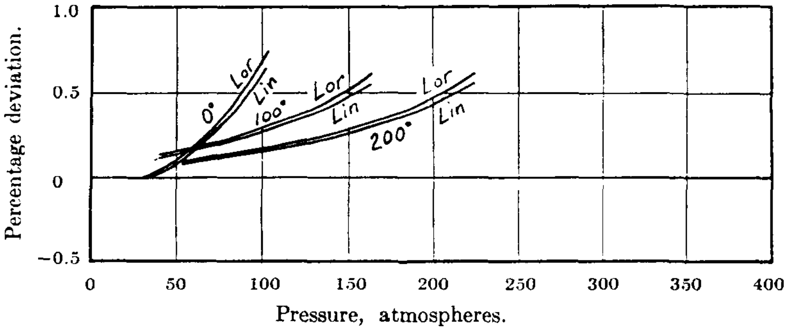

FIGURE 20. Keyes and Burke: 19.46% nitrogen, 80.54% methane at 0°, 100° and 200° C.

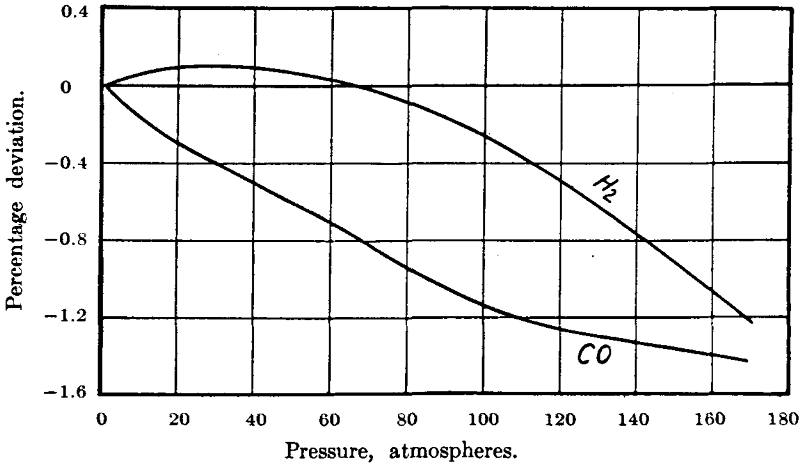

FIGURE 21. Scott: Hydrogen and carbon monoxide at 25° C.

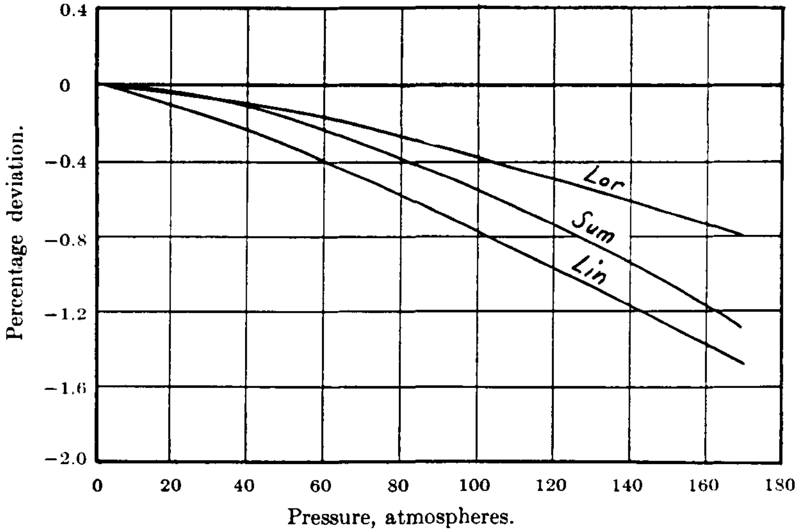

FIGURE 22. Scott: 66.3% hydrogen, 33.7% carbon monoxide at 25° C.

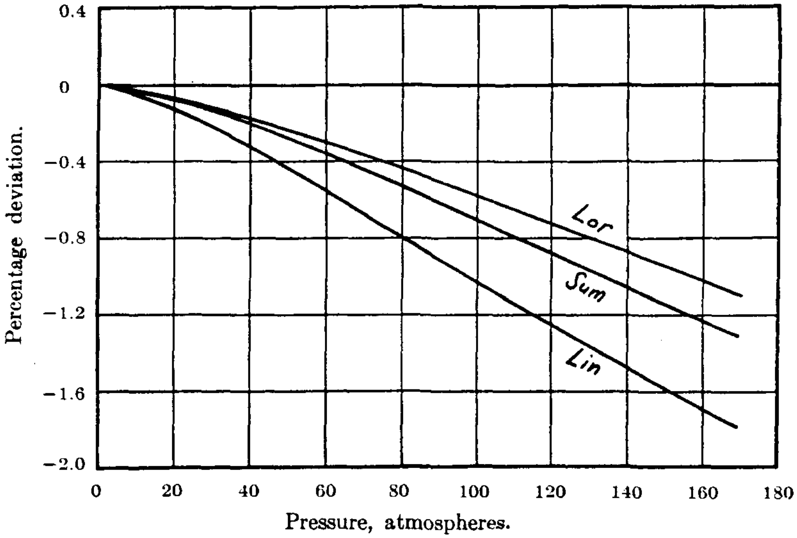

FIGURE 23. Scott: 51.7% hydrogen, 48.3% carbon monoxide at 25° C.

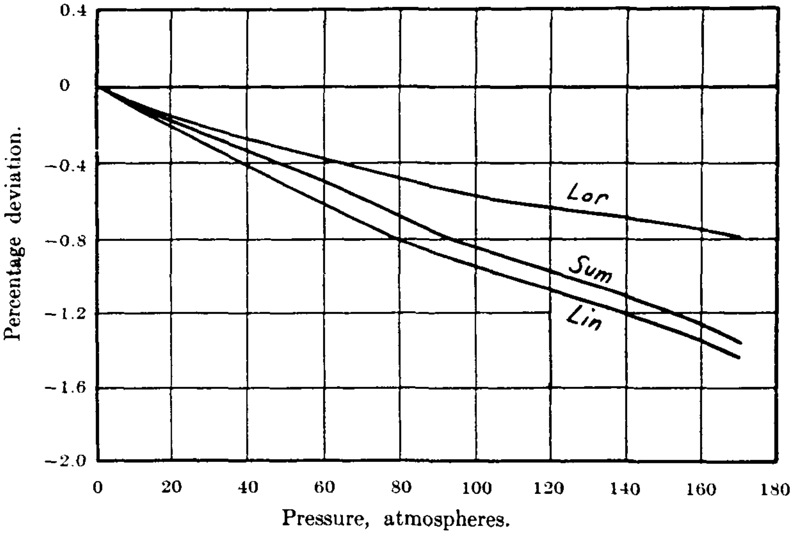

FIGURE 24. Scott: 33.1% hydrogen, 66.9% carbon monoxide at 25° C.

8. Discussion of the Graphs.

We shall first consider the results exhibited in the graphs with a view to determining which of the methods of combination of the constants of the equation of state gives the best representation of the pressures of the mixtures.

The constants a, b and c have in general so small an effect on the calculated pressure that the method of combination used for them is not important; hence throughout the present treatment linear combination is employed for each. Of the two methods of combination that could be used for A_0, linear or linear square root, the former is excluded because this would lead to zero or to negative intercepts for the expansion of gases on mixing at zero pressure; hence in all cases linear square root combination is used for A_0. For B_0 three methods have been proposed: linear, linear square root, and Lorentz. The plots have been drawn to exhibit the results for these methods of combining B_0.

For each mixture there is given two curves one representing the percentage deviation of the calculated from the observed pressure when linear combination is used for B_0 and the other when Lorentz combination for B_0 is used. In each case all of the other constants are combined according to the relations (19). The deviation curves resulting when linear square root combination is used for B_0 would in each case be about as far above the "Lor" curve as the "Lor" curve lies above the "Lin" curve. In the first place we notice that the differences between the results obtained by using the linear or Lorentz method of combination for B_0 are not great and that they increase with increasing differences in the values of B_0 for the gases composing the mixture.

The measurements of Keyes and Burke together with those of Smith and Taylor are the only set that extends over a sufficient temperature range to permit the determination of the values of the equation of state constants for the pure gases from data taken with the same apparatus as that employed for the mixtures. In Figures 18, 19 and 20 are shown the deviations of the calculated from the observed pressures for three of the five temperatures, 50° and 150° not being included. The average deviations for all temperatures and for the entire pressure range are given in Table VI. There is a slight trend in favor of linear combination for B_0.

TABLE VI.

Average Deviations of the Pressures Calculated by the Beattie-Bridgeman Equation of State from the Observed Values for the Nitrogen-Methane Mixtures.

Mole fraction		Average percentage deviation	
N_2	CH_4	Linear B_{0x}	Lorentz B_{0x}
1.0000	0.0000	0.11%	
0.5666	0.4334	.73	0.78%
0.2046	0.7954	.20	.21
0.1946	0.8054	.23	.26
0.0000	1.0000	.07	

For the discussion of the results of Masson and Dolley, of Verschoyle, and of Scott from the standpoint of the methods of combination of constants we are not in so favorable a position since it is necessary to employ values of the constants for the various pure gases determined from the data of other observers. It is generally true that two sets of compressibility data taken by different observers on the same gas do not agree with each other to the same order of accuracy as the consistency of each group of measurements within itself. For this reason the curve labeled "Sum" which is determined by $\Sigma(x_i\%_i)$ is added. It is not intended that this curve correct completely for the deviations of the equation of state from the compressibility data on the pure gases, but it is believed that unless otherwise noted weight should be given to the curve when discussing the deviation curves for the mixtures. For reasons given below the curves representing the Masson and Dolley data are not referred to the "Sum" curve; but those for the results of Verschoyle and of Scott are treated from this standpoint.

The values of the constants for ethylene determined[35] from Amagat's data do not give a satisfactory representation of Masson and Dolley's measurements on pure ethylene although they do lead to a good reproduction of the mixture data. This lack of agreement in the case of the pure ethylene may be due in part to the fact that the densities above 70 atmospheres at 25° C. are greater than the critical density and in part to the real disagreement between the data of Amagat and of Masson and Dolley. It will be noticed that the mixture equation gives a fairly good representation of the mixture containing as much as 90% ethylene and this suggests that perhaps there may be an error in the pure ethylene data. In any case it is evident that very little weight can be given the "Sum" curve when discussing the mixture data and hence the curves are compared with the axis representing zero deviation. An examination of the curves given in Figures 2 to 9 from this standpoint shows a trend in favor of linear combination of B_0.

The results of the treatment of the data of Verschoyle and of Scott are given in Figures 10 to 17 and Figures 21 to 24 respectively. In each case the deviation curves for the mixtures are to be compared with that labeled "Sum." There seems to be little choice in the method of combining B_0 for these mixtures since the curve marked "Sum" lies about half way between the "Lin" and "Lor" curves in every case except for the mixture containing 74.98% hydrogen—25.02% nitrogen when it coincides with the "Lor" curve.

The linear square root method of combination for B_0 leads to a deviation curve lying above the "Lor" curve. But the deviation curves resulting when Lorentz combination is used lie almost entirely above the experimental results, and hence linear square root combination for B_0 is not supported.

It is possible that one method of combination will give the best results for one pair of substances and another method for another pair. If however we wish to use one method for all mixtures, the evidence is slightly in favor of linear combination for B_0; and in view of the much greater simplicity of this method of combination it is the one recommended.

It seems reasonable to conclude that the Beattie-Bridgeman equation (18) for gas mixtures together with the method of combination (19) gives a satisfactory over-all correlation of the data for the cases studied, though the agreement may not be within the experimental error in some cases.

The question of whether or not the method of combination (19) reproduces the data on gas mixtures with sufficient accuracy for determining the general thermodynamic properties of mixtures cannot be treated in the present paper. Investigation by Lurie and Gillespie,[12] Gillespie,[35] and Gillespie and Beattie[44] indicate that the method of combination (19) does give satisfactory results in several cases. It is believed that the most severe test of an equation of state for mixtures is the representation of compressibility data. An equation that gives a fair reproduction of the pressure-volume-temperature data on gas mixtures will represent many other thermodynamic properties excellently.

9. LINEAR COMBINATION OF CONSTANTS COMPARED WITH DALTON'S AND WITH AMAGAT'S LAW.

The method of combination (19) may be called linear combination of constants. It is of interest to determine whether this method leads to substantially better results than Dalton's law of the additivity of pressures at constant volume and temperature or Amagat's law of the additivity of volumes at constant pressure and temperature.

Lurie and Gillespie,[12] and Keyes and Burks[16] have found that linear combination of constants in the Keyes equation of state gives better results than Dalton's or Amagat's law for mixtures of nitrogen with ammonia and of nitrogen with methane respectively. Gillespie[35] has shown that linear combination of constants in the Beattie-

Bridgeman equation of state gives a much better representation of the expansion of gases on mixing at low pressure than Amagat's law for argon-ethylene, oxygen-ethylene, nitrogen-methane and hydrogen-nitrogen mixtures.

Keyes and Burks do not discuss their compressibility data from the standpoint of Dalton's law of additive pressures; they use the law of "partial pressure" in terms of weight fractions. They also give comparisons (their Figure 1) of the volumes calculated by use of Amagat's law with the observed volumes for two of their mixtures. In Table VII are given the percentage deviations (read from their plot) of the volumes of the mixtures calculated by Amagat's law from the observed volumes; and the percentage deviations of the pressures of the mixtures computed by linear combination of constants in the equation of state from the observed pressures, these latter deviations being determined from our plots 18 and 20. Linear combination of constants gives a better representation of the nitrogen-methane data than Amagat's law; and, since Amagat's law should give better results for these mixtures than Dalton's law, it is safe to conclude that linear combination of constants gives a better representation than Dalton's law.

Masson and Dolley give for all of their mixtures the deviations resulting when Dalton's law and when Amagat's law are used. In Table VIII are given the average percentage deviations of the pressures of the mixtures calculated by Dalton's law from the observed pressures, and of the volumes of the mixture calculated by Amagat's law from the observed volumes. The deviations of the pressures calculated by linear combination of constants from the observed pressure are also given. The Dalton law and Amagat law percentages were obtained by dividing the deviations by the *calculated* pressures or volumes, whereas the linear combination percentage deviation were obtained by dividing by the *observed* pressures in the usual manner. Examination of Table VIII shows that linear combination of constants is far superior to either adding pressures or adding volumes.

Neither Verschoyle nor Scott treated their results from the standpoint of Dalton's or Amagat's law. Calculation for several points shows that for these mixtures linear combination of constants gives the best results but the superiority of this method is not so pronounced as for those mixtures containing ethylene.

TABLE VII.

Percentage Deviations Resulting from the use of Linear Combination of Constants in the Equation of State and of Amagat's Law for the Nitrogen-Methane Mixtures.

Temp., ° C. Pressure, atm.	Method	0°	100°	200°
			Percentage deviations.	
	A. 56.66% N_2, 43.34% CH_4.			
50	Amagat	1.30%	0.45%	0.25%
	Linear combination	0.25	0.25	0.20
100	Amagat		1.15	0.70
	Linear combination		0.60	0.40
	B. 19.46% N_2, 80.54% CH_4.			
50	Amagat	0.75	0.25	0.15
	Linear combination	0.05	0.10	0.05
100	Amagat		0.70	0.35
	Linear combination		0.30	0.15

TABLE VIII.

AVERAGE PERCENTAGE DEVIATIONS RESULTING FROM THE USE OF LINEAR COMBINATION OF CONSTANTS IN THE EQUATION OF STATE, DALTON'S LAW, AND AMAGAT'S LAW FOR THE ARGON-ETHYLENE AND OXYGEN-ETHYLENE MIXTURES.

The percentage deviations for linear combination of constants were given for every 5 atmospheres and are referred to the observed pressures; those for Dalton's law and Amagat's law were given for every 10 atmospheres and are referred to the additive pressure or volume.

Mole fraction		Average percentage deviations at 24.95° C. from 30 to 125 atmospheres.		
A	C_2H_4	Dalton's law	Amagat's law	Linear combination
0.7517	0.2483	4.5%	8.0%	0.4%
0.4992	0.5008	6.5	14.5	0.3
0.4002	0.5998	6.3	15.8	0.3
0.2918	0.7082	4.6	16.0	0.8
0.0989	0.9011	3.2	9.1	1.6
O_2	C_2H_4			
0.7463	0.2537	4.4	8.7	0.4
0.4996	0.5004	6.7	14.6	0.9
0.4004	0.5996	5.7	17.3	1.8

10. The Second Virial Coefficient.

Gibby, Tanner and Masson[40] have found a maximum in the second virial coefficient for helium-hydrogen mixtures at 25° C. Using the method of combination of constants (19) we can write the second virial coefficient β_x for a binary mixture in terms of the mole fractions:

$$\beta_x = RT[x_1B_{01} + (1 - x_1)B_{02}] - [x_1A_{01}^{1/2} + (1 - x_1)A_{01}^{1/2}]^2 - \frac{R}{T^2}[x_1c_1 + (1 - x_1)c_2] \quad (22)$$

Differentiating and equating to zero we find that β_x has a maximum or minimum value at

$$x_1 = \frac{1}{2} + \frac{\beta_1 - \beta_2}{2(A_{01}^{1/2} - A_{02}^{1/2})^2} \quad (23)$$

where β_1 and β_2 are the virial coefficients for the pure Gases 1 and 2 respectively. Moreover, this value of x_1 must correspond to a maximum value of β_x since the curvature

$$\left(\frac{d^2\beta_x}{dx^2}\right)_T = -2\,(A_{01}^{1/2} - A_{02}^{1/2})^2 \quad (24)$$

is always negative whatever the values of A_{01} and A_{02}.

The existing experimental data on binary mixtures indicate that the β_x vs. x_1 curve does not exhibit a maximum, except perhaps in certain temperature regions. From equation (23) we see that no maximum will exist for values of x_1 between zero and unity unless the numerical values of the last term of (23) is less than ½. Substitution of the numerical values of the constants for hydrogen and helium into (23) gives a calculated maximum at about 50% hydrogen. The plot given by Gibby, Tanner and Masson indicates a maximum for β_x at about 80% hydrogen. In a later publication,[45] Tanner and Masson "restate the data" of their earlier paper and give a corrected plot which indicates a maximum at about 70% hydrogen. The curvature is so slight that the maximum cannot be located with exactness. The lack of quantitative agreement between the calculated and the observed values of the maximum is probably due to one or both of two causes: (1) Deviation of the equation of state of hydrogen or helium from the data of Gibby, Tanner and Masson on the pure gases, and (2) the fact that these investigators used only two terms of the virial to represent their isotherms, whereas the equation of state virial contains four terms for hydrogen and three for helium.

Equation (23) calculates a maximum in the β_x curve for hydrogen-nitrogen mixtures at 97% hydrogen for 20° C. but no maximum at 0° C. Verschoyle's curves were drawn without a maximum, but the 20° curve almost admits of a maximum.

Gibby, Tanner and Masson, and Verschoyle each expanded pV in an ascending power series of the pressure but the second coefficient of this expansion should correspond to the β_x of equation (22) divided by RT.

11. SUMMARY.

The Beattie-Bridgeman equation of state (18) has been applied to the calculation of the pressures of gaseous mixtures of argon with ethylene, oxygen with ethylene, hydrogen with nitrogen, nitrogen with methane and hydrogen with carbon monoxide.

The equation of state constants a, b and c, which do not, in general, have a great effect on the calculated pressure were combined linearly with the composition of the mixture. In accordance with the results of several previous investigations, linear square root combination was used for A_0. The relative merits of linear, Lorentz, and linear square root combination for B_0 were studied by the use of deviation curves for all of the mixtures. On the whole, linear combination for B_0 was slightly favored over the Lorentz method, while the linear square root relation gave the least satisfactory results. It is pointed out that there is little theoretical evidence in favor of the Lorentz method.

Linear combination for each of the constants R, $A_0^{1/2}$, a, B_0, b and c of the Beattie-Bridgeman equation of state gives a satisfactory overall correlation of the compressibility data on gas mixtures, although in some cases the representation of the data may not be within the experimental error.

For all of the mixtures studied, linear combination of the constants of the equation of state gives a much better representation of the experimental data than either Dalton's law or Amagat's law.

It had been experimentally found that certain mixtures of helium and hydrogen have a larger second virial coefficient than the pure gases. The equation of state confirms the existence of such a maximum and predicts a similar phenomenon for other mixtures within certain temperature ranges.

The values of the equation of state constants for nitrogen give a satisfactory representation of the compressibility of carbon monoxide to 170 atmospheres at 25° C., a result which is not unexpected in view of Langmuir's theory of isosters.

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[20] Berthelot, Comptes Rendus Acad. Sci. Paris, *126*, 1703, 1857 (1898).

[21] Galitzine, Wied. Ann. der Physik, *41*, 770 (1890).

[22] Lorentz, Wied. Ann. der Physik, *12*, 127, 660 (1881).

[23] See for instance Trautz and Emert, Zeit. für anorg. u. allgem. Chem. *150*, 277 (1926); Trautz and Narath, Wied. Ann. der Physik, (4), *79*, 637, (1926); Eucken and Bresler, Zeit. für phys. Chem., *134*, 230 (1928).

[24] Phillips, Jour. of Math. and Physics, *1*, No. 1 (1921); see also Beattie and Bridgeman, Proc. Amer. Acad. Arts and Sci., *63*, 229 (1928).

[25] Beattie, Jour. Amer. Chem. Soc., *51*, 19 (1929).

[26] Beattie and Bridgeman, Jour. Amer. Chem. Soc., *49*, 1665 (1927); ibid., *50*, 3133 (1928). See especially Proc. Amer. Acad. Arts and Sci., *63*, 229 (1928).

[27] Smith and Taylor, Jour. Amer. Chem. Soc., *45*, 2107 (1923); ibid., *48*, 3122 (1926).

[28] Keyes and Burks, Jour. Amer. Chem. Soc., *49*, 1403 (1927).

[29] Lennard-Jones and Cook, Proc. Roy. Soc., London, *115 A*, 334 (1927).

[30] Deming and Shupe, Jour. Franklin Institute, *208*, 389 (1929).

[31] Kleeman, Jour. Franklin Institute, *206*, 511 (1928).

[32] Van Lerberghe, Bulletin d'Acad. roy. de Belgique (Classe de Sciences), (5) *15*, No. 6 (1929).

[33] Eucken and Bresler, Zeit. für phys. Chem., *134*, 230 (1928).

[34] Pollitzer and Strebel, Zeit. für phys. Chem., *110*, 768 (1924).

[35] Gillespie, Physical Review, *34*, 352 (1929). The values of the equation of state constants for ethylene are given by Gillespie, Jour. of Phys. Chem., *33*, 354 (1929).

[36] This work is summarized by Kuenen, "Verdampfund und Verflüssigung von Gemischen," Barth, Leipzig, *1906*.

[37] Kuenen, Verschoyle and van Urk, Comm. Phys. Lab. Univ. Leiden, No. *161*.

[38] Verschoyle. Proc. Roy. Soc., London, *111 A*, 552 (1926).

[39] Bartlett, Cupples and Tremearne, Jour. Amer. Chem. Soc., *50*, 1275 (1928).

[40] Gibby, Tanner and Masson, Proc. Roy. Soc., London, *122 A*, 283 (1929).

[41] Scott, Proc. Roy. Soc., London, *125 A*, 330 (1929).

[42] Beattie and Bridgeman, Jour. Amer. Chem. Soc., *50*, 3151 (1928).

[43] Langmuir, Jour. Amer. Chem. Soc., *41*, 868, 1543 (1919).

[44] Gillespie and Beattie, forthcoming publication.

[45] Tanner and Masson, Proc. Roy. Soc., London, *126 A*, 268 (1930).

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THE ANONYMOUS LA CONQUISTA DEL PERU (SEVILLE, APRIL 1534) AND THE LIBRO VLTIMO DEL SVMMARIO DELLE INDIE OCCIDENTALI (VENICE, OCTOBER 1534).

EDITED, WITH AN INTRODUCTION AND A BIBLIOGRAPHY,

BY ALEXANDER POGO.

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INTRODUCTION.

1. Early reports on the conquest of Peru.

The earliest reliable information concerning Quito and Cuzco was, apparently, gathered by Pascual de Andagoya, in 1522, when he went down the coast of the Mar del Sur, north of the equator. The preliminary explorations of the northern coasts of Peru by Francisco Pizarro, Diego de Almagro, and the pilot Bartholomé Ruiz followed, between 1524 and 1529, and led to the signing, in Toledo, on July 26, 1529, of the well-known capitulación between Queen Juana and Francisco Pizarro. The stage was set for one of the most spectacular events of the age of the great discoveries: the conquest of Peru and the destruction of the empire of the Incas by a small group of adventurers led by the Pizarro brothers.

The execution of Atahuallpa, on August 29, 1533, and the arrival in Spain, on January 9, 1534, of the "Santa Maria del Campo," with Hernando Pizarro and part of the Peruvian plunder aboard, can be considered as the end of the first act of the drama. Among the few hundred Spaniards who changed the course of the history of Peru in the years 1531–1533, there were several men able to record[1] the extraordinary events: Francisco Xerez and Pedro Sancho, the secretaries of the illiterate[1] governor Francisco Pizarro; Hernando Pizarro and Miguel Estete who saw and destroyed the idol at Pachacamac; Pedro Pizarro, the young cousin of the Pizarro brothers; and the anonymous author of *La conquista del Peru.*

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[1] There were others, of course, who could give oral reports; e. g., Diego de Molina, whose testimony was recorded by Oviedo, in Santo Domingo.

The reports of Xerez and of Estete will be discussed in connection with *La conquista del Peru,* item (B) of the Bibliography. The writings of Hernando Pizarro, Pedro Sancho, and Pedro Pizarro will be dealt with presently.

2. Hernando Pizarro, Pedro Sancho, Pedro Pizarro.

The letter (see item (U), end of remark) sent by Hernando Pizarro to the Audiencia Real in Sancto Domingo, and dated Sancta Maria del Puerto, November 23, 1533, is probably the first authoritative report of the conquest which became available to the European public. The demand for "nouuelles certaines des isles du Peru"[2] is shown by the Spanish, Italian, French, Dutch, and German leaflets and pamphlets[3] which appeared in 1534 and 1535.

The report (see items (P 6) and (T) of the Bibliography) of Pedro Sancho, dated Xauxa, July 15, 1534, is a sequel to the *Verdadera relacion* of Xerez, item (C), and covers the events of the second half of 1533 and of the first half of 1534; it is, therefore, of limited interest for the study of the anonymous *La conquista del Peru,* (B), which was published before Pedro Sancho's report was completed, and which represents an earlier phase of the conquest.

The report, (S), of Pedro Pizarro, a cousin of the Pizarro brothers, was completed in 1571; it has the value of recollections of a mature mind, but it lacks the qualities—and defects—of a report written while the conquistadores were marching on. It was first published in 1844.

3. La conquista del Peru, Seville, April 1534.

In the middle of the fourth decade of the sixteenth century, the number of detailed published reports by participants in the epic events in Peru appears as rather limited. Xerez, Estete, and the anonymous author of *La conquista del Peru* thus occupy a privileged position, and their writings deserve a careful study.

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[1] The art of writing remained a mystery to the marquess; his secretaries not only wrote his reports but even signed his name; he made the rúbricas. See M. J. Quintana, *Vidas de los españoles célebres,* tomo III, apendice I.

[2] Title of Harrisse 196.

[3] See, e. g., Harrisse 193, 195, 196, Harrisse Add. 107–109.

The popularity which the anonymous report, (B), enjoyed is shown by the Italian version, (F), published in October 1534, and reprinted in 1535, (I); by the French translation, (K), of the Italian version, (F) or (I); by the inclusion of (F) in Ramusio's collection, (P 4); and by the abbreviated translation of (P 4) in *Purchas his Pilgrimes.* The primitive woodcut on the title-page of (B) represents an incident which so impressed the contemporary and some of the later writers that even the very short *Copia delle lettere del prefetto della India*[1] devoted relatively much space to it; Purchas also forgot that he was supposed to give but "Briefe Notes,"[2] and told his readers how "The Frier (i. e., Vicente de Valverde) with a Booke in his hand, beganne to speake to him (i. e., to Atahuallpa) the things of God; hee demanded the booke, and the Father gaue it him, and he threw it downe about his people."

Two surviving copies of the original edition of *La conquista del Peru,* Seville, April 1534, are known to bibliographers—the once "unique" Grenville copy in the British Museum (G. 6589), and the "New York Public Library chronicle." The Grenville copy is listed under Francisco Pizarro in the catalogues[3] of the British Museum, and the difficulty of finding it had led to the belief[4] that it was lost, and that its former claim to uniqueness now rightfully belonged to the N. Y. P. L. copy.

The value of the anonymous *La conquista del Peru*—not of its interpolated Italian translation used by Prescott—as a source of first-hand information, has been recognized by R. B. Merriman who repeatedly quotes the "New York Public Library chronicle" in *The Rise of the Spanish Empire*, and who devotes a note to it, vol. 3, p. 614-615. "To all intents and purposes," he states, the N. Y. P. L. chronicle "can be classified as a manuscript"; "known to bibliographers, but not hitherto utilized by historians, at least in the original." One of the purposes of the present publication is to make the original accessible to students of Spanish-American history; in addition to a transcription of the black-letter "manuscript," to use R. B. Merriman's characterization of (B), it gives a reprint of (F) and reproduces the original Spanish sources used for the inflation of (F).

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[1] Harrisse 193 and Harrisse Add. 107.

[2] *Pilgrimes*, vol. 4, p. 1489-91, London, 1625.

[3] Henry Thomas, *Short-title Catalogue of Books printed in Spain*, p. 71, London, 1921. *Catalogue*, vol. 77, London, 1894.

[4] See, e. g., P. A. Means, Biblioteca Andina, *Transactions Connecticut Academy*, vol. 29, p. 362, 1928.

The authorship of the anonymous *La conquista del Peru* has been variously ascribed to Oviedo, Xerez, and Estete. It is possible to prove that none of the three mentioned authors could have written the anonymous chronicle.

4. Oviedo.

The name of Oviedo is inextricably interwoven with the bibliography of Xerez and Estete, because one of the 1547 editions of Xerez (with Estete's report incorporated, as usually) is annexed to one of the 1547 editions of Oviedo, (N), and because the reports of both Xerez and Estete are absorbed in Book 46 of Oviedo's *Historia general y natural de las Indias,* (U).

The name of Oviedo is connected with the anonymous translations of the anonymous chronicle, (B), by a series of bibliographical misunderstandings which began almost four centuries ago. The second title of the 1526 edition of Oviedo, (A), is apparently responsible for the titles of the tripartite Italian collection, (D), (E), and (F); the French translation, (K), of the anonymous third part, (F), mistaking (F) for a continuation of the second part, (E), has borrowed from the second title of (E) the information that it was written by "Gonzalo Fernando del Ouiedo natif de Madril," forgetting that the original report was written "de la main decelluy qui y fut present," which certainly does not apply to the alcayde of the fortress of the city of Santo Domingo. See Figs. 11 and 12.

It may be noticed, incidentally, that the modest place occupied by (F) at the end of a collection beginning with a "Libro primo" has led to its quotation by the title of (D), thus introducing the name of Pietro Martire, or even to the confusion of (F) with the *Libro primo de la conquista del Peru,* i. e., with the Gaztelu translation, (G) or (H), of the *Verdadera relacion,* (C), which leads us back to Xerez and Estete.

5. Xerez.

The signed MS of an official report of Xerez, written by order of the governor Francisco Pizarro, and dated Caxamalca, July 31, 1533, was in the hands of Oviedo when he wrote Book 46 of his *Historia general y natural*, (U).

The MS of Xerez, from which the July 1534 edition, (C), of the *Verdadera relacion* was printed by Bartholomé Perez, reached Seville, probably, on June 3, 1534, when the ship, of which Francisco Rodriguez was master, arrived with her owner, Xerez, aboard, and the latter's conquistadorial and secretarial shares in Atahuallpa's ransom as part of her precious cargo. This MS must have been, essentially, a copy of official documents such as the signed report of Estete on the Pachacamac-Xauxa expedition, and the signed report of Xerez himself, quoted by Oviedo, in (U).

The twenty-one stanzas attached to the edition (C) are important not only for the biography of Xerez, but also for the bibliography of his *Verdadera relacion.* They are introduced by six lines containing an allusion to the "maltreated honor" of Xerez, and a statement that the stanzas were composed by an hidalgo. This anonymous hidalgo, and not Xerez, is, apparently, referred to in the "dedication-title," "Dirige el autor sus metros al Emperador que es el Rey nuestro señor." We do not know why, in the 1547 editions, (L) and (M), the six lines with the reference to the altruistic hidalgo were omitted, the last twelve biographically valuable stanzas dropped, and the "dedication-title" kept, so that the remaining nine stanzas appear as if they were a contribution to poetry by the author of the *Verdadera relacion.* There is no valid reason for ascribing—with Gayangos and Vedia[1]—the authorship of the twenty-one stanzas to Oviedo, because that colonial official and prolific writer had no reason for posing, at the age of fifty-six, as an anonymous versifying hidalgo; moreover, we have no evidence that Oviedo knew Xerez.

6. Estete.

The inspector (veedor) Miguel de Estete was one of the few companions of Hernando Pizarro in the gold-gathering and iconoclastic anabasis to Pachacamac which led to the bloodless victory over Atahuallpa's best general, Calicuchima. Estete's report, in the form of a diary, was first published as an integral part of Xerez' *Verdadera relacion*, (C). The publication, more than three centuries later, in 1855, of the third part of Oviedo's *Historia general y natural*, (U), made available another version of the same diary, which seems to follow the original of Estete more faithfully than the Xerez edition. The original diary, as reproduced by Oviedo, gave the names of the days and the dates, with occasional characteristic slips; it gave the names of unimportant pueblos and of their caciques; it often used the "we" of a participant in the adventure instead of the "he" (Hernando Pizarro) of a chronicler of the expedition; these fine traits are polished off in the Xerez edition of Estete's diary, which also changed "romeria" to "peregrinacion," "rescio" to "furioso," "espantaban" to "marauillaban," etc. The Bibliography gives, in the remarks to (U), some material for the comparison of the two editions of Estete's diary; a study of the writings of Estete still remains to be made.

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[1] G. Ticknor. *Historia de la literatura española.* Vol. 2, p. 517. Madrid, 1851.

C. M. Larrea published, in 1918, a far more important work by Estete, (V), a transcript of which was used by Prescott who considered it, however, as the work of an anonymous author.[1] A careful study of the differences between the diary of Estete, in (C) and in (U), and the MS published by Larrea will be necessary in order to remove the possibility of doubts as to the authorship of (V). The Bibliography gives some information concerning the N. Y. P. L. transcript of the *N[oticia] del Peru*, (V), which is important because of the Spanish remark overlooked or disregarded by Prescott.

P. A. Means[2] ascribes to Estete a third work, the anonymous *La conquista del Peru*, our (B), and adds: "It is my present opinion, subject to revision on the presentation of valid contrary evidence, that this very quaint document is by Don Miguel de Estete." This brings us back to our anonymous chronicle, (B), and to the question of its authorship.

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[1] Wm. H. Prescott, *History of the Conquest of Peru*, vol. I, book III, ch. VI, note 7.

[2] Biblioteca Andina, *Transactions Connecticut Academy*, vol. 29, p. 361–63. Means seems, however, to confuse, occasionally, (B) and (V); thus, he ascribes to (B) "twelve folios in length," and thinks that "*La Conquista del Peru* is the original form of Estete's report and that, for some unknown reason, only an abbreviated version of it was included with Xerez's definitive publication." The seven pages of Estete's diary in (C) cannot be called an abbreviated version of the thirty lines devoted, in (B), to the expedition to Pachacamac. On the other hand, (V) is no more than (B) the "original form" of the "abbreviated version" in (C), because the short diary antedates the much more elaborate (V).

7. The anonymous author of La conquista del Peru.

We have already seen that Oviedo was not the author of (B), in spite of the claims of the French translation, (K). It still remains to be shown that neither Xerez nor Estete could have written the anonymous *La conquista del Peru.*

The similarity of the title-pages of (B) and (C)—see Figs. 2 and 3—and the fact that both (B) and (C) describe the same phase of the conquest, have led not only to repeated confusion of (B) and (C) by bibliographers who were satisfied with second-hand information, but also to the no less unfounded suggestion that (B) was a preliminary short edition of (C). This hypothesis originated, apparently, with Vedia,[1] who wrote about (B) without having seen it; his guess was approvingly repeated by Escudero y Perosso[2] and others. Those who have read both (B) and (C) have little use for the hypothesis that Xerez is the author of (B). In the 1927 Stevens' catalogue, *Rare Americana*, No. 350, Xerez is still given as the author of (F), which is a translation of (B), not of (C).

We have seen that Estete was a participant and chronicler of the anabasis to Pachacamac. The anonymous author of (B) did not take part in the expedition, but remained in Caxamarca: "y el gouernador les dio licencia: y lleuaron algunos sacristanes con quien el demonio podia medrar muy poco. El señor gouernador y todos los que con el quedamos nos viamos cada dia en mucho trabajo." The "valid contrary evidence" asked for by P. A. Means is given by the anonymous author himself. He relates the expedition to Pachacamac in thirty[3] lines, as an event described to him by others.

The anonymous author of (B) was one of the twenty-five compañeros who asked for the permission to return home immediately after the distribution of Atahuallpa's ransom; it is probable that he arrived at the "rio de Sevilla" on board the "Santa Maria del Campo," on January 9, 1534, in time to complete his chronicle, and to have it printed in April. He was "testigo de vista" of most of the things described in his report, which he does not claim to have completed in Peru: ". . . y otras muchas cosas se me han passado de la memoria." It is probable that he added in Spain—not in Peru or on his homeward voyage—the remarks about the iniquitous distribution of the plunder and sentences like "Mas digo que vi pesar y quedar alla del quinto de su magestad, sin lo que lleuo el señor Fernando piçarro, mas de ciento y ochenta mil pesos": Hernando Pizarro was aboard the "Santa Maria del Campo."

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[1] Enrique de Vedia. *Historiadores Primitivos de Indias.* Vol. 2, p. IX. Madrid, 1853.

[2] Francisco Escudero y Perosso. *Tipografia Hispalense.* No. 351. Madrid, 1864 (premiada) y 1894 (impresa).

[3] Fol. 5r, lines 26–30; fol. 5v, line 34 to fol. 6r, line 11.

The events of 1531–1533 have been represented, from four different points of view, by the military leader Hernando Pizarro, by Francisco de Xerez, the secretary to the governor, by Miguel de Estete, an inspector, and by the author of *La conquista del Peru,* an unknown soldier. The reports are as different as could be expected, taking into consideration the positions from which the events were observed, and the personalities of the observers. The anonymous *La conquista del Peru* is not only the earliest known detailed chronicle of the conquest; it has the advantage—as compared with the writings of Hernando Pizarro, Xerez, and Estete—of not being an official report; it even dares to criticize the actions of the governor; of course, it had to be submitted to the señores inquisidores del arçobispado de Seuilla, but otherwise it can be considered as a non-retouched picture.

La conquista del Peru was written by a man who was greedy and sullen;[1] his horizon and his vocabulary were rather limited; occasionally, he was ironical, even sarcastic;[2] his rank, although Ramusio promotes him to a captaincy, was probably that of a simple soldier—possibly, a horseman.[3] To recognize Xerez or Estete in the anonymous author of *La conquista del Peru,* is as difficult for a careful reader as to overlook the numerous details in which his chronicle, (B), differs from the essentially distinct reports included in (C).

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[1] See, e. g., fol. 6v, lines 43–44, or fol. 7r, lines 35–46.

[2] Fol. 4r, lines 26–27; fol. 5r, lines 22–23 and 36–37.

[3] He took part in the reconnaissance led by Hernando Pizarro and Hernando de Soto, fol. 2v, lines 33 ff.

I have mentioned the limited vocabulary of the anonymous author of (B). Among the words currently used both by Xerez and by Estete, but completely absent in *La conquista del Peru*, the following could be quoted: "abundoso," "agrio," "aspero," "comarca," "comida," "españoles," "mantenimiento," etc.; the word "menester" is used in (B) but once. On the other hand, the verb "lleuar" is so extensively used by the anonymous author, that it is repeated no less than six times in the twenty-five[1] lines devoted to the iconoclastic expedition, and could be rendered, by the Italian translator, by "condussero," "haueuano leuati," "portar," "haueua," "menerebbe," "hauea." Both Xerez and Estete use freely the designation "los españoles"; in (B) we find "los christianos" only. Both Xerez and Estete—especially Estete—compare the things they describe with similar and familiar things in Spain. One looks in vain for such recollections in the anonymous chronicle; the only apparent exception —the statement that the "pueblo donde la mezquita estaua . . . . es mayor que Roma"—is due to the fact that he is reporting the impressions[2] of one of the participants in the expedition to Pachacamac. Incidentally, he does not mention the name of the "pueblo donde la mezquita estaua"; the name Calicuchima is used but twice in (B); on the other hand, the reports of Xerez, and especially of Estete, are full of Indian names. Some of the passages from the *Verdadera relacion* reproduced on the Spanish pages of the present publication, below the text of *La conquista del Peru*, will give the reader an opportunity to compare the style of Xerez and Estete with the style of our anonymous author.

8. Translations and their sources.

The anonymous Italian translation (F) appeared, in October 1534, as *Libro vltimo* of a heterogeneous collection of translations and compilations, and it is, therefore, not surprising, that the editor of (F) took some liberties with the anonymous Spanish text of (B). He diluted the sometimes dry story by the generous use of a source of information which became available in July 1534—the *Verdadera*

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[1] Fol. 5v, line 34 to fol. 6r, line 11.

[2] Was this comparison suggested by the word "romeria" used, no doubt, by some of the participants, for the description of the "pilgrimage" to Pachacamac?

relacion, (C). Excerpts from the reports of Xerez and of Estete constitute about one third of (F). In the present publication, the original passages are reproduced, from the 1534 edition, (C), on the left pages, opposite the corresponding Italian pages, where the interpolations are printed in italics. In addition to these borrowings from (C), there are, in (F), numerous exegetic notes, supplied from the general store of knowledge of the translator and interpolator. There is a third type of additions, which serve as an introduction to and a conclusion of (F). To connect the *Libro vltimo*, (F), with the "libri precedenti," (D) and (E), the compiler gives a short geographical and historical sketch, which ends with the introduction of the anonymous author of (B) as "persona prudente & pratica che vi fu presente." To borrow an expression from the second title of the *Libro primo*, (D), the beginning and the end of (F) are compiled "da molte particulari relationi"—which were not always wisely used. Thus, the final addition giving a seaman's description of the return of the alleged "author" contains, among several other objectionable statements, the two following anachronisms: Pedrarias, dead since 1531, could be of little assistance to the homeward bound conquistadores in 1533; the treasure ship arrived at the "rio de Sevilla" on January 9, 1534, not on January 15. The concluding passage of (F) is hardly derived from Spanish sources, and was added, in all probability, for the benefit of the "infiniti mercatanti Fiorentini, Genouesi, & Venetiani" who were expected to read the *Libro vltimo*. It should not be forgotten that there were "pasajeros y personas particulares" on board the "Santa Maria del Campo," who brought a third of a million pesos of gold, and who probably were not overlooked, as a source of information, by some of the "infiniti mercatanti"; we know that printed news[1] concerning the "zway schyff" which arrived in Seville on June 3, 1534, were available, in 1535, even in Dutch and German translations made from French versions of Spanish letters; it can therefore be assumed that the anonymous interpolator of (F) had ample oral, written and printed material at his disposal for patching together a not too homogeneous story of a typical homeward voyage.

The *Libro vltimo*, (F), was probably printed by Nicolo d'Aristotile, detto Zoppino. It is possible that Giovanni Battista Ramusio was the translator, interpolator, or editor of (F).

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[1] See Harrisse Add. 108.

The typographically inferior edition, (I), of the *Libro vltimo* printed in Rome, in May 1535, is a reprint of (F). Its title-page (see Fig. 7) shows the influence of the Gaztelu translation, (G), of Xerez which became available in March 1535.

The Ramusio version, (P 4), of the anonymous chronicle is a reprint of (F). It may be mentioned, incidentally, that the Ramusio version, (P 5), of the *Verdadera relacion* is an independent translation of (C), and not a reprint of (G); Ramusio, apparently, agreed with Gaztelu who admits, in his dedication addressed to the famous doge Andrea Gritti, that his version "de lingua Spagnola in la commune italiana" is far from being perfect, due to "la poca pratica che ho di tal lingua"; the Milan publisher of (H), a reprint of (G), was not as discriminating as Ramusio. The Ramusio version, (P 4), of the anonymous chronicle differs considerably from (F) in spelling and punctuation; the more important variae lectiones are given in the footnotes to the Italian pages of the present publication. The Ramusio editions of 1565 and 1606 are reprints of (P 4); they correct some of the misprints of the 1556 edition, leave others unchanged, and introduce a few misprints of their own.

The French translation, (K), of the anonymous chronicle was made —as shown by its title, Fig. 10— from the Italian version, i. e., from (F) or (I). The translator, whose initials were I. G., has been tentatively identified with Jacques Gohorry or with Jean de Gorris (Gorraeus); in *Les Bibliothéques Françoises de La Croix du Maine* etc., Paris, 1772, vol. I, p. 411–414, p. 512, bio-bibliographical data[1] on these two interesting Frenchmen can be found; it is possible that one of them made the translation, (K). The French translation follows the Italian text of (F) closely, but does not hesitate to become occasionally free, as can be seen from a selection of quotations given in the footnotes to the Italian pages of the present publication. The literary style of I. G. is charming, and his tendency to exaggerate is as amusing as his efforts to avoid references to the Cesarea Maiesta of Charles V. Some information concerning the only known original copy of the interesting French map of Peru (by the Conte d'Alsineys?), and its facsimiles, is given in the Bibliography, item (K).

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[1] Less complete data can be found in the first edition, Paris, 1584, v. 1, p. 186–187, p. 230.

The abbreviated English translation, by Purchas, of the Ramusio version, (P 4), of (F), was mentioned on p. 179 of this Introduction. See the Bibliography, item (X), for the recent English translation, by J. H. Sinclair, of the anonymous chronicle, (B).

9. Remarks concerning the present publication.

Transcription. For typographical reasons, all the Spanish, Italian, and French abbreviations were spelled out; this does not interfere with the historical accuracy of the texts and quotations; readers who are interested in the philological or typographical aspects of the documents, will have to consult the originals, or—with some restrictions[1]—their facsimiles; in the Bibliography, the letters added by the spelling-out of the abbreviations were enclosed in parentheses. Otherwise, the spelling—including misspellings—of the originals, as well as capitalization, accentuation, punctuation, etc. were carefully followed. Misprints were not corrected, except in the cases marked by individual footnotes; inverted letters, and the confusion of **n** and **u** were eliminated; damaged letters were restored. For the sake of legibility, fused words were separated, and after-punctuation spaces introduced.

Facsimiles. About one half of the facsimiles reproduced here are published for the first time. Plates I, II, IV, and VI may be of interest to bibliographers because of the juxtaposition of facsimiles which belong together.

The margins were reproduced in the case of (B), in order to show the state of preservation of the illustrated cover; in the case of (C), to permit a comparison with the beautiful and correct reproduction of the title-page of the Church-Brown copy in the *Biblioteca Andina* of Means, and with its large but incomplete facsimile in Church; and, in the cases of (H) and (N), where the absence or presence of the last line is important. In the remaining facsimiles, the margins had to be omitted.

Reductions to 1/3, 1/2, 2/3, and 3/4 the actual size were used; because of the stretching and shrinking of drum-dried dull photostats, the ratio of the two dimensions of the original is not preserved in the facsimile; although the error is practically negligible, I prefer to use expressions like "about 1/3 actual size." The dimensions, in millimeters or inches, of the variously cut individual copies will be found in the standard bibliographies; a comparison of the linear dimensions of the letterpress-titles of (D), (E), and (F) would be meaningless; the border blocks of a title-page seldom form a rectangle, and the lower edges of the title-pages of (C), or of (G) and (H), or of (N) and (O), need special definitions. The indication of the scale of the facsimiles seems to be an acceptable compromise.

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[1] See Bibliography, item (X), remark concerning the objectivity of the facsimile.

Acknowledgments. I express my gratitude for the books, maps, photostats, and information put at my disposal by the Harvard Library, the New York Public Library, the John Carter Brown Library, the William L. Clements Library, the Hispanic Society of America, the British Museum, and the Bibliothèque Nationale. I sincerely appreciate the interest in the present publication shown by Professor J. D. M. Ford and by Professor C. H. Haring of Harvard, and especially by Dr. G. Sarton of the Carnegie Institution of Washington.

BIBLIOGRAPHY.

Synopsis of the Bibliography.

Item	Year	Author	Translator or editor	Sources	Language
(A)	1526	Oviedo			Sp.
(B)	1534	Anonymous			Sp.
(C)	1534	Xerez			Sp.
(D)	1534	Anghiera	Unknown		It.
(E)	1534	Oviedo	A. Navagero	(A)	It.
(F)	1534	Anonymous	Unknown	(B)	It.
(G)	1535	Xerez	Gaztelu	(C)	It.
(H)	1535	Xerez	Gaztelu	(C)	It.
(I)	1535	Anonymous	Unknown	(F), (G)	It.
(J)	1535	Oviedo			Sp.
(K)	1545	Anonymous	I. G.	(F)	Fr.
(L)	1547	Xerez		(C)	Sp.
(M)	1547	Xerez		(C)	Sp.
(N)	1547	Oviedo, Xerez		(M), (O)	Sp.
(O)	1547	Oviedo		(J)	Sp.
(P 1)	1556	Anghiera	Ramusio	(D)	It.
(P 2)		Oviedo		(E)	
(P 3)		Oviedo		(J), (O)	
(P 4)		Anonymous		(F)	
(P 5)		Xerez		(C,) (M)	
(P 6)		Sancho			
(Q)	1749	Xerez	Barcia	(C), (M)	Sp.
(R 1)	1837	Xerez	Ternaux-Compans	(M), (G)	Fr.
(R 2)	1842	Xerez	Piccini?	(M), (P 5)?	It.
(R 3)	1842	Xerez	Kulb	(M)?	Ger.
(R 4)	1853	Xerez	Vedia	(C), (M)	Sp.
(R 5)	1872	Xerez	Markham	(M)	Eng.
(R 6)	1891	Xerez	Unknown	(C)?, (M)	Sp.
(R 7)	1917	Xerez	Urteaga	(R 6), (U)	Sp.
(S)	1844	Pedro Pizarro	Navarrete		Sp.
(T)	1849	Sancho	Icazbalceta	(P 6)	Sp.
(U)	1851–55	Oviedo	Amador de Los Rios		Sp.
(V)	1918	Estete	Larrea		Sp.
(W)	1924	Estete	Urteaga	(V)	Sp.
(X)	1929	Anonymous	Sinclair	(B)	Sp., Eng.

(A) Gonzalo FERNANDEZ de OVIEDO y VALDES.
Ouiedo dela natural hystoria delas Indias.
Toledo. Remon de Petras. February 15, 1526.
Harrisse 139. Church 59. Brown[1] 89.

(*Title-page:*) OUiedo dela natural hystoria delas Indias. Con preuilegio dela S. C. C. M. *Arms of Spain. Border, with medallion for autograph signature.*

(*Verso of t.-p.:*) SUmario dela natural y general istoria delas Indias. que escriuio Go(n)çalo Ferna(n)dez de Ouiedo alias de Ualdes natural dela villa de Madrid vezino y regidor dela cibdad d(e) santa Maria del antigua del Darien: en tierra firme. dando relacion a la .S. C. C. M. del Emperador don Carlos nuestro señor de algunas cosas que el dicho autor vido y ay enlas indias. Lo qual visto y esaminado enel consejo real delas Indias su .M. mando que fuesse impresso porque a todos los hombres fuesen notorias tan grandes y marauillosas y nueuas cosas: y que ninguna otra persona lo pudiesse imprimir ni vender ni traer de fuera destos reynos sino el dicho Go(n)çalo fernandez o quien su poder ouiere so graues penas: como mas largamente se contiene enel preuilegio real que para esto ay de su Magestad.

(*Colophon:*) ¶ El p(re)sente tratado intitulado Ouiedo dela natural hystoria d(e)las indias se imprimio a costas del autor Go(n)çalo Ferna(n)dez de Ouiedo al(ia)s de Ualdes. Por industria de maestre Remo(n) de petras: y se acabo enla cibdad de Toledo a .xv. dias del mes de Hebrero. de .M. D. xxvj. años.

(*Recto of* Fo. lij.:) S. C. C. R. M. YO he escripto eneste breue sumario o relacion, lo que de aquesta natural istoria he podido reduzir ala memoria: y he dexado d(e) hablar en otras cosas muchas de que enteramente, no me acuerdo, ni tan al proprio como son se pudieran escreuir: ni expressarse tan largame(n)te como estan enla general y natural istoria de Indias que de mi mano tengo escripta, segun enel prohemio y principio deste reportorio dixe: lo qual tengo enla cibdad de santo Domingo dela ysla Española. . .

Folio. **Gothic.** Title, red and black letters. Total (Harvard Library copy), 54 leaves; numbered, Fo. ij.-Fo. lij. Woodcuts in the text.

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[1] John R. Bartlett, *Bibliotheca Americana.* Second edition, Part I, Providence, 1875.

Woodcuts. The double-headed eagle of the arms of Spain is triple-crowned. The orientation of the single-headed eagle of the crowning border block corresponds to that of the golden fleece. The "reversed" woodcut used at the end of (B) was probably copied from the title-page of (A).

Facsimiles and autographs. Title-page and colophon reproduced in Church, p. 139 and 140; title-page also in Winsor,[1] v. 2, p. 344. Neither shows the signature "Fernandz,"[2] with rúbrica, in the medallion at the base of the border. In the Harvard Library copy, Oviedo's signature is partially covered by the arms of Don Diego Cruzat who became the owner of the book before 1537.[3] The signature of Oviedo is adorning the medallion of the title-page of the John Carter Brown copy. The Harvard Library copy has Oviedo's autograph corrections of misprints in the text.

Watermark. Gauntlet surmounted by a flower.[4]

Remarks. (A) is not a summary of (J). (J) is the first edition of the MS mentioned in the dedication, Fo. lij., quoted above. The second titles of (D) and (E), and both titles of (F) were obviously suggested by the second title of (A).

(B) ANONYMOUS.
La conquista del Peru. llamada la nueua Castilla.
Seville. Bartholomé Perez. April, 1534.
Harrisse 199.

(*Title-page:*) See Fig. 2.

(*Colophon, fol.* 8v:) See Fig. 1.

Folio. **Gothic.** Total (N. Y. P. L. copy), 8 unnumbered leaves. Inside of illustrated cover, i. e., fol. 1v and fol. 8r, blank. Signatures, A ij., A iij., and A iiij.

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[1] Justin Winsor. *Narrative and Critical History of America.* Vol. 2. Boston, 1886.

[2] The initial looks like a monogram composed of G, o, z, and F.

[3] In 1537, Don Diego added a bordure azure, with three crosses of Jerusalem or, to his escutcheon; they do not appear on the Harvard Library copy of (A).

[4] There are several varieties of this watermark, differing in size, in the position of the thumb, the shape of the wrist, etc.; the flower has always five petals and its stem reaches the middle finger. A book sometimes contains more than one variety of this gauntlet-and-flower watermark.

Woodcuts. The large woodcut, on the title-page and on fol. 7v, represents Atahuallpa, borne in a litter by armed Indians, ready to throw away the Bible, facing the Dominican fray Vicente de Valverde and a few armed Spaniards; a fortress in the background. The block from which the arms of Spain on fol. 8v were printed was probably a direct copy from the title-page of (A); on the escutcheon of the double-headed, triple-crowned eagle, dexter and sinister are interchanged, so that the caste and the lion occupy the sinister chief point; the golden fleece is oriented in the usual way; the pillars of Hercules are missing. For the tail-piece of fol. 7v the same blocks were used as for the printing of the illustrated cover, i. e., of fol. 1r and of fol. 8v. The angels on both sides of the arms of Spain look in the same direction as the corresponding head of the eagle, i. e., "outward," away from the central "vertical" line; compare the "inward" orientation of the same angels flanking the Atahuallpa group on the title-page of (C). The block at the bottom of fol. 8v was designed as a side-block.

Facsimiles. The N. Y. P. L. has published, in 1929, a facsimile edition of (B); see item (X) of this Bibliography. The first and last pages of the illustrated cover of (B) are reproduced here, Fig. 2 and 1, by courtesy of the N. Y. P. L.

Watermark. Gauntlet surmounted by a flower.

(C) Francisco de XEREZ.
Verdadera relacion de la conquista del Peru.
Seville. Bartholomé Perez. July, 1534.
Harrisse 198. Church 70.

(*Title-page:*) See Fig. 3.

(*Verso of* C2:) . . . el capita(n) Herna(n)do piçarro . . . dio al gouernador la relacio(n) q(ue) miguel estete veedor (q(ue) co(n) el fue en el viage) hizo: la q(ua)l es la siguiente. ⸿ La relacio(n) del viage que hizo el señor capitan Herna(n)do piçarro por ma(n)dado del señor gouernador su hermano desde el pueblo de Caxamalca a Parcama y de alli a Xauxa.

(*Recto of* C6:) La q(ua)l dicha relacio(n) yo Miguel d(e) estete veedor q(ue) fui en el viage q(ue) el dicho capita(n) Herna(n)do piçarro hizo truxe de todo lo susodicho: de la manera q(ue) sucedio. Miguel estete. Prosigue el primer autor.

(*Last six lines of the text,* C8r1:) Y porq(ue) en esta ciudad de Seuilla algunos con embidia o malicia: y otros con ignorancia de la verdad, en su absencia ha(n) maltratado su honra vn hidalgo dolie(n)do se de afrenta ta(n) falsa co(n)tra ho(m)bre q(ue) ta(n) honradame(n)te y ta(n) lexos d(e) su natural ha biuido, hizo e(n) su d(e)fensa los siguie(n)tes metros.

(*Dedication-title of the stanzas,* C8r1:) ¶ Dirige el autor sus metros al Emperador q(ue) es el Rey n(uest)ro señor.

Folio. **Gothic.** Double columns; C8v, three columns of stanzas. Total (N. Y. P. L. and J. C. B. copies), 19 unnumbered leaves.

Woodcuts. The large woodcut of the title-page, identical with the one used twice in (B), represents the first meeting of Atahuallpa and fray Vicente de Valverde; it does not represent the first meeting of Atahuallpa and Fernando Pizarro, as stated by H. H. Urteaga. Corresponding to the "inward" grouping of the Indians and Christians, the side-blocks with the angels, borrowed from the cover illustration of (B), are interchanged, thus achieving the same unity of composition as in the case of the "centrifugal" double-headed eagle group. The upper border of (C) has, in the left corner, the arms of Pope Clement VII (Nov. 18, 1523–Sept. 25, 1534), a bastard of Medici who adopted the arms of his cousin Leo X (1513–1521), the son of Lorenzo the Magnificent; this corner-woodcut, and the statement of Xerez that his ship arrived in Seville on June 3, 1534, would be sufficient to give the summer of 1534 as the time of printing of (C), if direct information (July, 1534) were missing. In the right upper corner of the border, the imperial eagle of Charles V is holding the pillars of Hercules in his claws. In the center of the upper border, the Assumption of the Virgin Mary.

Facsimiles. Title-page and end of text, with first stanza, reproduced in Church, p. 162 and 163; the Church copy is in the J.C. Brown Library since 1911. Title-page of the Church-Brown copy, in P. A. Means, *Biblioteca Andina,* plate VI. The title-page of the N. Y. P. L. copy is reproduced here, Fig. 3, in order to facilitate the comparison with the title-page of (B). The third known copy of (C), in the British Museum, has a facsimile title-page, by John Harris, Sr.

Watermark. Gauntlet surmounted by a flower.

Remarks. The reality of Escudero 350, the "ghost" edition of 1534, on 45 leaves, folio, by the same printer, Bartholomé Perez, is discussed in the remarks to (R6).

(D) Pietro MARTIRE D'ANGHIERA.
Libro primo della historia de l'Indie occidentali.
No place, no date. (Venice, Nicolo Zoppino, 1534).
Harrisse 190. Church 69.

(*Title-page:*) See Fig. 4.

(*Verso of t.-p.:*) SVMMARIO DE LA GENERALE HISTORIA DE L'INDIE OCCIDENTALI CAVATO DA LIBRI SCRITTI DAL SIGNOR DON PIETRO MARTYRE DEL CONSIGLIO DELLE INDIE DELLA MAESTA DE L'IMPERADORE, ET DA MOLTE ALTRE PARTICVLARI RELATIONI.

4to. Total (Harvard Library copy), 80 leaves; numbered, 2–79; last leaf, blank.

Facsimiles. Title-page and verso, in Church, p. 159 and 160. Title-page, Fig. 4, by courtesy of the N. Y. P. L.

Remarks. (D) is usually bound with (E), and sometimes (F) is added; the three books are then quoted by the title of the first, which leads sometimes to confusion. The title of (D) has also led to confusion with (G). The Harvard Library copy of (D) is bound with (E) and (F). Running head: DE L'INDIE OCCIDENTALI LIBRO PRIMO. According to Quaritch's *General Catalogue*, Part XV (*Monuments of the early printers*), Nos. 36709–10, London, 1888, the printer of (D), (E), and (F) "was probably Niccolo Zoppino, to judge from a comparison of the types with those which he used in books that bear his name."

(E) OVIEDO, author. Andrea NAVAGERO, translator.
Libro secondo delle Indie occidentali.
Venice. December, 1534.
Harrisse 190. Church 69.

(*Title-page:*) See Fig. 5.

(*Verso of t.-p.:*) See Fig. 11.

(*Beginning of leaf* 66r:) STampato in Vinegia, nel mese di Decembre, Del. 1534.

4to. Total (Lenox copy), 66 leaves and 2 maps; numbered, 2 to 64; verso of last leaf, blank.

Woodcuts and maps. Four large woodcuts and two woodcut maps. The map of the ISOLA SPAGNVOLA is not the first detailed map of the island; it appears, however, to be the first known map showing S. DOMINICO; a reproduction, from the original block, can be found in Ramusio, (P2). Of the large map two original copies are known; they are in the N. Y. P. L. and in the John Carter Brown Library; this map is dated, December 1534, and has the following title: La carta uniuersale della terra ferma & Isole delle Indie occide(n)tali, cio è del mondo nuouo fatta per dichiaratione delli libri delle Indie, cauata da due carte da nauicare fatte in Sibilia da li piloti della Maiesta Cesarea; copyright notice: Con gratia & priuilegio della Illustrissima Signoria di Venetia p(er) anni. XX. The John Carter Brown copy of this map is hand-colored, and is not bound with (E).

Facsimiles. Title-page, Fig. 5. The verso of the t.-p. of (E) is reproduced here, Fig. 11, by courtesy of the N. Y. P. L., in connection with a misleading footnote in (K), shown in Fig. 12. There are good lithographic reproductions of the large map, from the facsimile tracing by John Harris, Sr. The colophon and the map notice, leaf 66*r*, are reproduced in Church, p. 161; the British Museum has a copy of (E) with five additional lines at the top of leaf 66r; the type was borrowed from leaf 63v, to keep the colophon and the map notice in place, and the printer forgot to cover it after inking; he was anxious to get the *Libro secondo* off the press—it was December, two months since the publication of the *Libro vltimo.*

Remarks. (E) is a translation of (A), made—in or before 1529—by Andrea Navagero (see Horatio F. Brown, *The Venetian Printing Press,* p. 103, London, 1891). (E) is usually bound with (D), and sometimes (F) is added. The Lenox copy of (E), with both the small and the large maps, is bound with (D) and (F). Running head: DE L'INDIE OCCIDENTALI LIBRO. II. The printer was probably Nicolo d'Aristotile, detto Zoppino,[1] see remark to (D).

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[1] Spelling of the colophon of the June, 1534 edition of Bordone's *Isolario.*

(F) ANONYMOUS.
Libro vltimo del svmmario delle Indie occidentali.
Venice. October, 1534.
Harrisse 190. Church 69.

(*Title-page:*) See Fig. 6.

(*Beginning of recto of leaf* Aij:) LIBRO VLTIMO DEL SVMMARIO de le cose de le Indie occidentali, doue si narra tutto quello ch'è stato fatto nel trouar la prouincia de Peru, ouer del Cusco, chiamata hoggi nuoua Castiglia, dalli capitani del Imperatore.

(*Colophon:*) ℂ In Vinegia, Del mese d'Ottobre. M D XXXIIII.

4to. Total (Harvard Library copy), 15 unnumbered leaves; verso of t.-p. and of last leaf, blank.

Facsimiles. Colophon, in Church, p. 161. Title-page, Fig. 6, by courtesy of the N. Y. P. L.

Remarks. (F), an interpolated anonymous translation of (B), possibly by G. B. Ramusio, is sometimes bound with (D) and (F). Running title: LIBRO DE L'INDIE OCCIDENTALI. The printer was probably Nicolo d'Aristotile, detto Zoppino, see remarks to (D) and (E). (F) is sometimes quoted by the title of (D), and confused with (G). (I) is a reprint of (F). (K) is a translation of (F). (F) was reprinted by Ramusio, (P4); Purchas made an abbreviated translation of (P4).

(G) XEREZ, author. Dominico de GAZTELU, translator.
Libro primo de la conquista del Peru.
Venice. Stephano da Sabio. March 27, 1535.
Harrisse 200. Church 73. Brown 116.

(*Title-page:*) LIBRO PRIMO DE LA CONQVISTA del PERV & prouincia del Cuzco de le Indie occidentali. *Woodcut.* Con gratia & priuilegio per anni X.

(*Verso of t.-p.:*) Nessun ardisca di stampare il presente volume o far stampar ne stampato da altri dare a vendere in li loghi del nostro dominio sotto la pena che nel breue appare.

(*Second title, leaf* 2r:) LA ADMIRABILE AMPLA ET VERA NARRATIONe della conquista del PERV & prouintia del Cuzco chiamata la noua Castiglia, conquistata per il molto magnifico & valeroso caualliero Francesco Picciarro caualliero della citta de Trugillo de Spagna come capitano general della Cesarea & catholica maiesta del Imperador Carolo q(ui)nto Re di Spagna &c. mandata a sua Maiesta per Francesco de Xerez secretario del supradetto signor capitano generale. Nella quale si contengono molte cose degne di admiratione circa le cittadi eggregie di quelle prouintie & costumi di habitatori, & massimamente de la gran quantita de oro, & argento & molte pietre di valore & ricche minere che in quelle bande sono ritrouate & gli fatti degni de memoria che li Spagnoli hanno fatto nella detta conquista, e quali deletteranno mirabilmente il lettore. Fu vista, corretta & essaminata questa opera per il Reueditore che sopra cio e posto in Seuilla laquale e stata sta(m)pata in la medsiema citta per Bartholomeo Perez in lingua volgare Spagnola. Et tradotta nouame(n)te in lingua Italiana per Dominico de Gaztelu gentilhomo Spagnolo de la citta de Tudela del reame de Nauarra secretario del illustrissimo signor don Lope de Soria co(n)sigliero & imbasciadore della prefata Cesarea Maiesta, appresso la illustrissima Signoria di Venetia nel anno MDXXXV. A di XXVII. di Marzo.

(*Colophon:*) Stampato in Vinegia per Maestro Stephano da Sabio del MDXXXV. Nel mese di Marzo.

4to. Total (Harvard Library copy), 62 unnumbered leaves; verso of leaf 4, blank.

Woodcuts. The double-headed eagle of Emperor Charles V is flanked by isolated PLVS VLTRA pillars of Hercules; dexter and sinister of escutcheon interchanged; golden fleece missing; medallion with a view of a fortified port, and the motto: IN OMNEM TERRAM EXIVIT SONVS EORVM; compare Fig. 8, a reproduction of the Milan imitation, (H). On leaf 2v, an escutcheon (a castle) and the name of Dominico de Gaztelu. On leaf 3r, a coat of arms and the initials of the doge Andrea Gritti to whom the translation is dedicated. On leaf 62v, an escutcheon with the printers name on a crown.

Facsimiles. Title-page, second title, and colophon, in Church, p. 169–171. Title-page, in Brown, facing p. 118. Compare the title-page of (H), our Fig. 8.

Remarks. (G) is a translation of (C). (H) is a reprint of (G), whereas the Ramusio version, (P5), is an independent translation. The report of "Michael stette reueditor" is given on leaves 43v–55r.

The leather binding of the Harvard Library copy was originally stamped with the initials H. T. below a ram's head couped; this copy was probably consulted by Ternaux-Compans for his translation of Xerez, (R1).

(H) XEREZ, author. GAZTELU, translator.
Libro primo de la conquista del Peru.
Milan. Gotardo da Ponte. 1535.
Harrisse 201.

(*Title-page:*) See Fig. 8.

(*Colophon:*) See Fig. 9.

4to. Total (N. Y. P. L. copy), 40 unnumbered leaves. Verso of t.-p., blank.

Woodcuts. The woodcut of the title-page, reproduced here in Fig. 8, is a good imitation of the one in (G). The woodcut below the colophon is reproduced in Fig. 9.

Facsimiles. The title-page and the last page are reproduced in Figs. 8 and 9, by courtesy of the N. Y. P. L.

Remarks. (H) is a reprint of (G). The reference to the "gratia & priuilegio per anni X", and to the Venetian prohibition were omitted from the title-page and from its verso. Typographically, (H) is inferior to (G).

(I) ANONYMOUS.
Libro vltimo de le Indie occidentale.
Rome. May, 1535.
Sunderland 265.

(*Title-page:*) See Fig. 7.

(*Colophon:*) ¶ Stampato in Roma nel mese di Magio. M.D. XXXV.

8vo. Total (N. Y. P. L. copy), 24 unnumbered leaves.

Facsimiles. Title-page of N. Y. P. L. copy, Fig. 7.

Remarks. The N. Y. P. L. copy differs, apparently, from the copy described in the *Bibliotheca Sunderlandiana,* No. 265, p. 20–21, London, 1881. The same edition, though possibly with a different title-page, is quoted in Palau y Dulcet, *Manual del librero Hispano-Americano,* vol. 3, p. 215, Barcelona & London, 1925, as follows: Summario de le cose de le Indie Occidentali. Libro vltimo de le Indie Occidentali intitulato Noua Castiglia. Roma. 1535. *8vo.*

(I) is a reprint of (F). Running head of (I): LIBRO DE L'INDIE OCCIDENTALI. The text of (I) states, like (F), "Arriuammo in Sibilia alli quindici giorni di Genaio .1534. doue furono discaricati tutti li ori & argenti. . ." The text of (I) was apparently set or even printed, when a Venetian copy of Gaztelu, (G), published in the last days of March, 1535, came into the hands of the Roman printer; the date of the arrival "in Spagna"[1] of the ship, January 9, 1534, given on the title-page of (I), and the wording of the title of (I) prove that the Roman printer has read the end of the text and the second title of (G). Typographically, (I) is inferior to (F).

(J) Gonzalo FERNANDEZ de OVIEDO y VALDES.
La historia general delas Indias.
Seville. Juan Cromberger. September 30, 1535.
Harrisse 207. Church 71. Brown 114.

(*Title-page:*) La historia general delas Indias. *Arms of Spain. Elaborate border.* Con priuilegio imperial.

(*Verso of t.-p.:*) PRimera parte dela historia natural y general delas indias yslas y tierra firme del mar oceano: escripta por el capitan gonçalo hernandez de Ouiedo y valdes: alcayde dela fortaleza dela ciudad de sancto Domingo dela ysla Española, y cronista dela sacra cesarea y catholicas magestades del emperador don carlos quinto de tal no(m)bre: rey de españa: y dela serenissima y muy poderosa reyna doña Juana su madre nuestros señores. Por cuyo mandado el auctor escriuio las cosas marauillosas que ay en diuersas yslas y partes destas indias e imperio dela corona real de castilla: segu(n) lo vido y supo en veynte y dos años y mas que ha biue y reside en aquellas partes. La qual historia comiença enel primero descubrimiento destas indias: y se contiene en veynte libros este primero volumen.

(*Colophon, verso of* Fo. cxcj.:) . . . Lo qual todo fue visto y examinado enel consejo real de indias: y le fue dado preuilegio para que ninguna otra persona lo pueda imprimir, sino el o quien su poder ouiere, so graues penas. La qual se acabo e imprimio enla muy noble y muy leal cibdad de Seuilla, enla empre(n)ta de Juam Cromberger, el postrero dia del mes de Setiembre. Año de mil y quinientos y treynta y cinco Años .·. ✠

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[1] Gaztelu: " . . . a di noue di Genaro arriuo a la fiumara de Seuiglia la seco(n)da naue nominata santa Maria del campo . . . ".

(*Beginning of recto of* Fo. cxcij.:) Epistola. ¶ Siguese vna carta missiua con que el cronista y auctor destas historias embio este volumen y primera parte dellas, assi como se acabaron de impremir. ¶ Al reuerendissimo e illustrissimo señor el cardenal de España don fray Garcia Jofre de Loaysa. . .

(*End of recto of* Fo. cxciij.:) . . . De seuilla a treynta dias del mes de Setiembre: de .M.d. y treynta y cinco años. *Handwritten:* R(euerendissi)mo & Ill(ustrissi)mo Señor las manos de .V.S. R(euerendissi)ma Besa Fernandz.[1] *Rúbrica.* There are copies, e. g., in the Library of the Hispanic Society and in the John Carter Brown Library, in which Oviedo omitted the word R(euerendissi)ma after the .V.S.

Folio. **Gothic.** Double columns. Title in red letters. Total (Harvard Library copy), 197 leaves; numbered, Fo. j-Fo. cxciij.; the Libro primo is a prohemio o introducion to the primera parte, is addressed to the .S. .Ces. .Ca. .R. .M. of Charles V, and occupies 3 unnumbered leaves following the title-leaf. Woodcuts in the text.

Woodcuts. Title-page: the orientation of the chief border block corresponds to that of the golden fleece of the arms of Spain; initials of the printer, I C, on an escutcheon of the base block; initials of the engraver, .S.M..D., in a lateral block. Arms of Columbus on the recto of Fo. x. Arms of Oviedo on the verso of Fo. cxciij.

Facsimiles. Title-page, colophon, and autograph, in Church, p. 165 and 166. Title-page, in Brown, facing p. 116. The arms of Oviedo (with the Southern Cross) and the last five lines of the letter to the cardinal, with autograph, from the Harvard Library copy, in Winsor, vol. 2, p. 345 and 346. A facsimile reproduction of an "irreverent" autograph dedication can be found in (U), vol. 1, p. cxii.

Watermark. Gauntlet surmounted by a flower.

Remarks. (J) is the first edition of the MS mentioned in the letter of dedication of (A). A second edition of (J) appeared in 1547, our (N) and (O). The first edition of the complete work appeared in 1851–55, our (U). As already stated, (A) is not a summary of (J).

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[1] See also item (A), footnote concerning Oviedo's signature.

(K) Authorship erroneously ascribed to OVIEDO. Translated by I. G.
L'histoire de la Terre Nevve dv Perù.
Paris. Pierre Gaultier (for) Iehan Barbé & Vincent Sertenas.
1545.
Harrisse 264. Brown 138.

(*Title-page:*) See Fig. 10.

(*Privilege, dated:*) Fait en parleme(n)t le troisiesme iour de Feurier. 1545.

(*Dedication, beginning and end:*) A Messire A. de M. C. & G. M. de F . . . Vostre treshumble seruiteur. I. G.

(*Preface, dated:*) A Paris ce XXI. de Ianuier M.D.XLV.

(*Lower recto of leaf with signature* B ij:) See Fig. 12.

(*Colophon:*) Imprimé à Paris par Pierre Gaultier, pour Iehan Barbé & Vincent Sertenas. 1545.

12 mo. Total (Maitland copy, N. Y. P. L.), 56 unnumbered leaves. Map.

Map. The Bibliothèque Nationale has the only known original copy of this map. The N. Y. P. L. facsimile is an excellent pen-and-ink tracing, apparently by John Harris, Sr.; it is not "a photographic copy," as erroneously stated on p. 47 of J. H. Sinclair's edition, (X), of the anonymous chronicle, (B). Under the right-hand title of the map, a signature, Conte d'Alsineys, in the handwriting of the engraver. The elliptical seal of the Bibliothèque Nationale appears on the original map.

Facsimiles. A reduced reproduction of the N. Y. P. L. facsimile of the map can be found in the J. H. Sinclair edition, (X). The title-page of (K) is reproduced here, Fig. 10, by courtesy of the N. Y. P. L. The erroneous reference to Oviedo is reproduced in Fig. 12.

Remarks. (K) is a translation of (F). An unfortunate afterthought—of the translator, the printer, or the publishers—transmitted to posterity in the two lines of fine type near the signature B ij, ascribed the authorship of the *Libro vltimo,* (F), to Oviedo, (F) being considered as a continuation of (E). The second title of (E) is the obvious source of the B ij footnote. See Figs. 11 and 12, and p. 180 of the Introduction.

(L) Francisco de Xerez.
Verdadera relacio(n) de la co(n)quista del Peru.
No place, no date. (Salamanca, Juan de Junta, 1547)?
Harrisse Add. 162. Huth v. 5, p. 1627–28.

(*Title-page:*) See Fig. 13.

(*End of the text; dedication-title:*) ¶ La vna delas dos naos postreras q(ue) llegaron (en la qual vino por maestre Francisco rodriguez) es de Francisco de Xerez natural desta ciudad de Seuilla: el qual escriuio esta relacion por mandado del gouernador Francisco piçarro estando en la prouincia de la nueua Castilla en la ciudad d(e) Caxamalca por secretario del Gouernador. A dios gracias. ¶ Dirige el autor sus metros al Emperador rey n(uest)ro señor.

4to. **Gothic.** Total, 38 unnumbered leaves; last leaf, blank. Stanzas in two columns on leaf 37, recto and verso.

Woodcuts. Ships before a fortress. Border. See Fig. 13.

Facsimile. Title-page, Fig. 13, by courtesy of the William L. Clements Library; probably the first published facsimile reproduction of the title-page of (L).

Watermark. According to Harrisse, who is quoting Robert S. Turner, the paper is watermarked, a flower surmounting a finger. The watermark is not mentioned in the Huth *Catalogue* or in Sotheby's sale *Catalogue of the Huth Library.* Suspecting that the watermark is one of the many varieties of a gauntlet surmounted by a flower, I have asked R. G. Adams, Custodian of the William L. Clements Library, to send me tracings of the watermark; it is a gauntlet surmounted by a flower, similar to those found in (A), (B), (C), (J), (N), and (O).

Remarks. The former Huth copy of (L) is the only one known to bibliographers. According to Harrisse, this edition "seems to have been printed likewise at Salamanca by Juan de Junta, probably a little before the folio edition of 1547," i. e., before our (M). In quoting Harrisse, the Huth *Catalogue* gives Seville instead of Salamanca as the place of publication; this mistake is repeated in the Sotheby *Catalogue* (p. 2263, lot 8218), and is, apparently, the source of the statement, "Sevilla, siglo XVI," in Palau y Dulcet.

In (L), like in (M), the last 12 stanzas of (C) are omitted. The omission of the six lines introducing the "hidalgo" makes the use of the word "autor," in the dedication-title, ambiguous.

(M) Francisco de Xerez.
Conquista del Peru. Verdadera relacion.
Salamanca. Juan de Junta. July 5, 1547.
Harrisse 277.

(*Title-page:*) See Fig. 15.

(*Recto of* Fo. xvj.:). . . el capitan Herna(n)do piçarro . . . dio al gouernador la relacion que miguel estete veedor (que con el fue en el viage) hizo: la qual es la siguiente. ¶ La relacion d(e)l viaje que hizo el señor capitan Hernando piçarro por mandado del señor gouernador su hermano desde el pueblo de Caxamalca a parcama y de alli a Xauxa.

(*Recto of* Fo. xx.:) La qual dicha relacion yo Miguel de estete veedor que fui en el viage que el dicho capitan Hernando piçarro hizo truxe de todo lo susodicho: de la manera que sucedio. Miguel estete. Prosigue el primer auctor.

(*Colophon:*) A gloria de Dios y dela virgen Maria se acabo el presente tractado llamado La conquista del Peru. Fue Impreso en Salamanca per Juan de Junta: acabose a cinco dias del mes de Julio año de nascimiento de nuestro señor Jesu Christo de Mil y Quinientos y quarenta y siete años .·. ✠ *Printer's device.*

Folio. **Gothic.** Double columns. Total (Boston Public Library copy), 23 leaves; numbered, Fo. ij.–Fo. xxij.

Woodcuts. Title-page: cavalry in the center, tents to the left, armed Indians to the right, fortress in the background; printer's monogram on escutcheon in medallion of chief border block; base and lateral blocks same as on title-page of (N). See Figs. 14 and 15. After the colophon: the head of John the Baptist on a charger, the monogram of Juan de Junta on an escutcheon, and the printer's device, NICHIL SINE CAVS[A].

Facsimiles. Title-page, in Brown, facing p. 144; printer's device, ibid., p. 144. Title-page, see Fig. 15.

Watermark. Some copies of (M) or of the second part of (N), e. g., in the Boston Public Library, the Library of the Hispanic Society (two copies out of three), the N. Y. P. L. (one of the two copies), the John Carter Brown Library, have a watermark—an escutcheon with fleur-de-lis—on Fo. xvij. The signature, c, of Fo. xvij shows that the corresponding hypothetical Fo. xxiiij would be a blank leaf at the end of the book; the watermarked brand of paper was apparently used, in an emergency, when the printing of the book was almost completed.

Remarks. (M) differs from (C) chiefly by the omission of the six lines introducing the piece of poetry, and by the omission of the last 12 stanzas. The text of (M) ends, like the text of (L), with "A dios gracias," and the dedication-title of the stanzas, "❡ Dirige el auctor sus metros al Emperador Rey nuestro señor," is closer to (L) than to (C). (M) is identical with the second part of (N).

(N) OVIEDO. XEREZ.
Coronica delas Indias. Y con la conquista del Peru.
Salamanca. Juan de Junta. May 2 and July 5, 1547.
Harrisse 278. Brown 145–146.

(*First title-page:*) See Fig. 14.

(*Verso of first t.-p.:*) PRimera parte de la hystoria natural y general delas Indias yslas y tierra firme del mar oceano: . . . segun lo vido y supo en veynte y dos años y mas que ha que biue y reside en aquellas partes . . .

(*Colophon, recto of* Fo. clxxxvj.:) . . . Lo qual todo fue visto y examinado enel consejo Real de Indias: La qual se acabo e Imprimio enla muy noble Ciudad de Salamanca en casa de Juan de Junta, a dos dias del Mes de Mayo Año de mil y quinientos y quarenta y siete Años. ✠

(*Following* Fo. cxcij.:) Conquista del Peru. Verdadera relacion, by Xerez, with title-page, separately paged, identical with (M).

Folio. **Gothic.** Double columns. First title, red and black letters. Total (Harvard Library copy), 196 numbered leaves (Oviedo) +23 numbered leaves (Xerez). Woodcuts in the text of Oviedo.

Woodcuts. First title-page: arms of Spain; same border blocks as on the second title-page, i. e., as in (M), right and left interchanged; see Fig. 14. Arms of Colombus on the recto of Fo. x. of Oviedo, with the base border block of the two title-pages of (N). Title-page of Xerez, identical with that of (M); see Fig. 15.

Facsimiles. Title-page of Xerez, in Brown, facing p. 144. Arms of Columbus, in Brown, p. 143. The title-pages of Oviedo and of Xerez, are reproduced here, Figs. 14 and 15, by courtesy of the Harvard Library; note the symmetry in the arrangement of the lateral border blocks.

Watermarks. In Oviedo, gauntlet surmounted by a flower. Some copies of Xerez have an escutcheon with fleur-de-lis on Fo. xvij; see (M).

Remarks. (N) consists of the 2nd edition of (J) and of (M). The 1547 edition of Oviedo appeared also, with a slightly different title-page, without (M); see (O).

(O) Gonzalo FERNANDEZ de OVIEDO y VALDES.
Coronica delas Indias.
Salamanca. Juan de Junta. May 2, 1547.
Harrisse Add. 163.

(*Title-page:*) Coronica delas Indias. *Arms of Spain. Border.* ¶ La hystoria general de las Indias agora nueuamente impressa corregida y emendada. 1547.

Folio. **Gothic.** Double columns. Title in red and black letters. Total, 196 leaves, numbered Fo. j.–Fo. cxcij. Woodcuts.

Remarks. (O) is the first part of (N), with a correspondingly different title-page.

(P) Giambattista RAMUSIO, translator and editor.
Terzo volume delle navigationi et viaggi.
Venice. Giunti. 1556. (Also, 1565, 1606). *Folio.*

(P 1) (1r–43v:) SOMMARIO DELLA HISTORIA DELL'INDIE OCCIDENTALI Cauato dalli libri scritti dal Sig. Don Pietro Martire Milanese, del Consiglio delle Indie, prima del Re Catholico & poi della Maestà dell Imperadore.

Remarks. (P 1) is a reprint of (D). The running head is as follows: SOMMARIO DELL'INDIE OCCIDENTALI DEL S. DON PIETRO MARTIRE.

(P 2) (44v–74r:) SOMMARIO DELLA NATVRALE ET GENERALE Historia dell'Indie Occidentali, composta da Gonzalo Ferdinando de Ouiedo, altrimenti di valde, natio della terra di Madril, habitatore & rettore della città di Santa Maria antica del Darien, in terra ferma dell'Indie, ilqual fu riueduto & corretto per ordine della Maestà dell'Imperadore, pel suo real Consiglio delle dette Indie.

Remarks. (P 2) is a reprint of (E). The map of ISOLA SPAGNVOLA is reprinted on 44r, from the original block. Running head: SOMMARIO DELL' INDIE OCCIDENTALI DEL S. GONZALO DE OVIEDO.

(P 3) (74v–224v:) DELLA GENERALE ET NATVRALE HISTORIA Delle Indie à tempi nostri ritrouate, . . .

Remarks. (P 3) is a translation of the first part of Oviedo's Historia natural y general, our (J), (N), and (O). Running head: DELLA HISTORIA DELLE INDIE LIBRO . . .

(P 4) (371v–378v:) RELATIONE DI VN CAPITANO Spagnuolo della conquista del Peru.

Remarks. (P 4) is a reprint of the anonymous translation (F) of the anonymous chronicle (B). Running head: DELLA CONQVISTA DEL PERV RELATIONE. In the index of the authors, Ramusio gives the title as follows: *Di vn Capitano Spagnuolo Relatione del discoprimento & conquista del Perù, fatta da Francesco Pizzarro, & da Hernando Pizzarro suo fratello.* The condensed version in *Purchas his Pilgrimes*, vol. 4, p. 1489–91, London, 1625, is based on (P4).

(P 5) (378v–398v:) LA CONQVSTA DEL PERV ET PROVINCIA Del Cusco chiamata la nuoua Castiglia, scritta & drizzata à sua Maesta da Francesco di Xerez, secretario del Capitan Francesco Pizarro, che questi luoghi conquisto.

Remarks. (P 5) is a translation—not a reprint of Gaztelu's version, (G) or (H),—of Xerez' *Verdadera relacion*, (M) rather than (C). The report of Michele di Estete Proueditore, 392v–396r, is entitled: LA RELATIONE DEL VIAGGIO, CHE FECE il Capitan Fernando Pizarro per ordine del Gouernatore suo fratello, da che partì dal popolo di Caxamalca per andare à Xauxa finche ritornò. The running head, DELLA CONQVISTA DEL PERV RELATIONE, is the same for the translations of the anonymous chronicle, (P 4), of Xerez and Estete, (P 5), and for their sequel, the translation of Pedro Sancho's report, 398v–414v. An abbreviated translation of (P 5) can be found in *Purchas his Pilgrimes*, vol. 4, p. 1491–94, London, 1625; a marginal note on p. 1493 reads: " . . . *Pachacamac.* Estetes discourse of that Voiage is at large in *Ramusio*, here omitted."

(P 6) (398v–414v:) RELATIONE PER SVA MAESTA DI QVEL che nel conquisto & pacificatione di queste prouincie della nuoua Castiglia è successo, & della qualità del paese dopo che il Capitano Fernando Pizarro si partì & ritorno à sua Maesta. Il rapporto del conquistamento di Caxamalca & la prigione del Cacique Atabalipa.

Remarks. The original Spanish MS, with signatures, used for this translation, is lost—probably, in the fire which occurred in the stamperia de Giunti, in 1557, and in which the MS of the Fourth volume of Ramusio is said to have perished. An abbreviated version of (P 6) appeared in *Purchas his Pilgrimes*, vol. 4, p. 1494–97, London, 1625. A complete Spanish translation of (P 6), by Icazbalceta, appeared in Mexico, 1849, (T). There is a phantastic plan of Cuzco, based on descriptions of Caxamarca, on fols. 411v–412r of Ramusio. (P 6) ends as follows: Si fini questa relatione nella città di Xauxa alli quindici di Luglio .1534. laquale, Pero Sancho scriuano Generale in questi regni della nuoua Castiglia & Secretario del Gouernator Francesco Pizarro per suo ordine & de gli officiali di sua .M. la scrisse giustamente come passò, laqual finita lesse alla presenza del Gouernatore & de gli officiali di .S.M. di parola in parola, & per esser così, il detto Gouernatore, & gli officiali di .S.M. si sono sottoscritti di sua mano. Francesco Pizarro, Aluaro Ricchelme, Antonio Nauarro, Garzià di Salsedo. Per commandamento del Gouernator & officiali Pero Sancho. Questa translatione è cauata dall' originale.

(Q) Andres Gonzalez BARCIA, editor.
Historiadores Primitivos de las Indias Occidentales. Tomo III. Madrid. 1749.

Remarks. The CONQUISTA DEL PERU by Francisco de Xerez is reprinted on pp. 179–219. Due to a confusion in pagination, pp. 211–219 are marked 229–237. Except for the 18th-century spelling, Barcia's edition differs but little from (C) or (M). The six lines of the Seville, 1534 edition, which introduce the piece of poetry, and which are missing in the Salamanca, 1547 edition, reappear in Barcia; on the other hand, it has but 9 stanzas of 10 verses, like (M).

(R) Modern editions and translations of XEREZ.

(R 1) 1837. Henri TERNAUX-COMPANS, translator.
Relation véridique de la conquête du Pérou . . . par F. Xérès.
Paris, Arthus Bertrand. 1837. *8vo.* VIII + 198 pp.

Remarks. Vol. 4 of *Voyages, Relations et Mémoires originaux pour servir à l'histoire de la découverte de l'Amérique.* Publiés pour la première fois en Français, par H. Ternaux-Compans. The translator used the Salamanca, 1547 edition (the printer is erroneously given as "Francisco Fernandez de Cordoue," p. VIII, whereas the name of Juan de Junta appears, p. 198, in the translation of the colophon); where the Spanish text was obscure, the Venetian version of Gaztelu (copy now in the Harvard Library?) was consulted. In order to ascribe the authorship of (B) to Xerez, Ternaux-Compans shifts the date of Xerez' arrival in Seville from June 3 to January 9, 1534; see his preface, p. VII.

(R 2) 1842. F. C. MARMOCCHI, editor. O. PICCINI, translator.
Relazione del conquisto del Peru e della Provincia di Cuzco . . .
Prato. 1842.

Remarks. Vol. 5 of the *Raccolta di Viaggi dalla scoperta del Nuovo Continente fino a di nostri*, compilata da F. C. Marmocchi. According to José Toribio Medina, this edition is a reprint of the Gaztelu translation. I have not seen (R 2); the Lenox copy could not be located in the N. Y. P. L.

(R 3) 1842. Hermann HAUFF, editor. Ph. H. KULB, translator.
Geschichte der Entdeckung und Eroberung Perus von Francisco de Xerez, Pizarro's Geheimschreiber.
Stuttgart. J. G. Cotta. 1842. *8vo.*

Remarks. Lieferung 27 of the *Reisen und Laenderbeschreibungen der aelteren und neuesten Zeit.* I have not seen (R 3).

(R 4) 1853. Enrique de VEDIA, editor.
Historiadores primitivos de Indias. Tomo II.
Madrid. 1853.

Remarks. Vol. 26 of the *Biblioteca de Autores Españoles.* The *Conquista del Perú,* by Francisco de Jerez, is reprinted on pp. 320–348. The spelling is modernized. The six lines introducing the piece of poetry are omitted, following (M), but the 21 stanzas of (C) are given. Pascual de Gayangos and Enrique de Vedia recognized the biographical value of the 12 stanzas omitted in the Salamanca edition, and inserted them in the adiciones y notas to their translation of Ticknor (*Historia de la Literatura Española,* vol. 2, 514–18, Madrid, 1851). Vedia claims that the folio edition printed by Bartholomé Perez, Seville, 1534, consists of 45 leaves. See also remark to (R 6).

(R 5) 1872. Clements R. MARKHAM, editor and translator.
Reports on the Discovery of Peru.
London, Hakluyt Society. 1872.

Remarks. Narrative of the conquest of Peru. By Francisco Xeres. Pages 1–109; the Narrative by Miguel Estete, pp. 74–94. Annotated translation of the 1547 edition.

(R 6) 1891. Anonymous editor.
Colección de libros que tratan de América raros ó curiosos. Tomo I.
Madrid. Juan Cayetano García. February 26, 1891.

Remarks. Curious, though not rare edition (tirada de 500 ejemplares, on very poor paper). Title on p. 3: "VERDADERA RELACION de la Couqnista del Perú por Francisco de Xerez Uno de los Primeros Conquistadores. Segun la primera edicion impresa en Sevilla en 1534. Madrid 1891." Announcement on p. 5: "Reproducimos á continuacion la portada de la primera edicion hecha en Seuilla el año de 1534 en letra gótica." Title-page reproduced on p. 7: "¶ Uerdadera relacion de la coquista del Perv y Provincia del Cuzco llamada la Nueva Castilla, coquistada por Francisco de Picarro, capitan de la S. C. C. M. del Emperador Nuestro Señor embiada á S. M. por Fraucisco de Xerez uno de los primeros conquistadores Anno 1534 Con Privilegio Real en Seuilla por Bartolomé Perez"; the vignette preceding the date is modern; the privilegio-notice is in roman type. In the Noticia bibliográfica por orden cronológico de las ediciones que se han hecho de esta obra, p. 13, the only Spanish edition of 1534 mentioned is "1ª. edición. *Verdadera relacion de la conquista del Perú,* fecha por Francisco de Xerez; en Sevilla, por Bartolomé Perez, 1534, folio gótico, 45 hojas sin numeracion." The text of this curious 1891 reprint, with "dialogues" in the style of modern novels, is followed by the 21 stanzas of the 1534 edition, but the six introductory lines are missing, like in the 1547 edition; according to the preface, p. 10, 11, the additional stanzas were copied from "la *Historia de la Literatura Española,* de Ticknor, tomo I, pagina 514."

Escudero mentions, under No. 350, the following edition of Xerez: "Verdadera relacion de la conquista del Piru y prouincia de Cuzco, llamada nueua Castilla, conquistada por Francisco Pizarro. . . . e(m)uiada a su Magestad por . . . natural de Sevilla secretario del sobredicho capitan . . . etc. Ympressa en Seuilla en casa de *Bartholomê Perez.* Año de 1534.", also en folio; 45 hojas; letra de Tortis.

The title of Escudero 350 differs both from (C) and from the title reproduced on p. 7 of (R 6). The number of leaves of Escudero 350 and of the original of which (R 6) claims to be a reprint, is reminiscent of the undated Huth copy, (L), which is a 4*to*., however. It is hard to escape the conclusion that Escudero and the editor of (R 6) refer either to the same copy or to two copies with different title-pages of an elusive 1534 folio edition, printed by Bartholomé Perez, in Seville, and consisting of 45 leaves. See also remark to (R 4).

Volume 2 of the *Colección de libros que tratan de América raros ó curiosos,* Madrid, 1891, is a reprint of the 1641 edition of the NVEVO DESCVBRIMIENTO DEL GRAN RIO DE LAS AMAZONAS. POR EL PADRE CHRSTOVAL de Acuña. The title-page, reproduced on p. XV "reducida a la mitad del tamaño del original," differs somewhat in spelling, punctuation, the use of capitals, italics, and the modern vignette, from the title-page of the Harvard Library copy, but the wording, line by line, is faithfully reproduced. The same can be said of the reproductions of original title-pages in other volumes of the *Colección de libros que tratan de América raros ó curiosos.* The assumption seems therefore to be justified that the title-page reproduced on p. 7 of (R 6) is far more valuable, bibliographically, than the French and English title-pages dated Salamanca, 1547, and inserted in Ternaux-Compans, (R 1), and Markham, (R 5), respectively.

(R 7) 1917. Horacio H. URTEAGA, editor.
Las Relaciones de la Conquista del Perú. . .
Lima. Sanmarti y Ca. 1917.

Remarks. Volume 5 of the *Colección de libros y documentos referentes a la Historia del Perú.* Pages 1–121 give a reprint of the Verdadera relación, with 21 stanzas, but without the introductory six lines at the end of the report. The spelling is modernized. Page 1 reproduces the title of (C), but ends with the words: "SECRETARIO DEL SOBREDICHO SEÑOR EN TODAS LAS PROVINCIAS Y CONQUISTA DE LA NUEVA CASTILLA." The paragraphing, with "dialogues," is the same as in (R 6). The text of Estete's report is a carelessly[1] proof-read reprint from Chapters 11 and 12 of Book 46 of Oviedo, (U); the ironical remark Oviedo's about the excessive length of the month of January in southern Peru is reproduced in (R 7), without any indication that it was not made by Xerez; on the other hand, the following passage, p. 88, is borrowed from Xerez and is missing in Oviedo: "Muchas cosas se podrían decir de las idolatrías que se hacen a este ídolo; mas por evitar prolegidad no las digo, mas de cuanto se dice entre los indios que aquel idolo los hace entender que es su Dios y que los puede hundir si le enojan y no le sirven bien y que todas las cosas del mundo están en su mano." Although (R7) is a compilation from (R 6) which claims to follow "la primera edicion impresa en Sevilla en 1534," and from (U) which claims to give the true report of Estete, "en fin, yo digo lo questa relaçion diçe," neither H. H. Urteaga's preface nor C. A. Romero's bio-bibliographical notice on Xerez informs the reader that (R 7) is a bibliographical hybrid.

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[1] Page 92, line 12, to page 93, line 10, should precede page 91, line 12, to page 92, line 11. In the text of Xerez, (R 7) has several lost passages, due to "jumps" from one group of words to a similar group in the next line or a few lines below in the original text.

(S) Pedro PIZARRO, author. NAVARRETE, editor.
Relación del descubrimiento y conquista de los reinos del Perú.
Madrid. 1844.

Remarks. In Navarrete's *Coleccion de documentos inéditos para la historia de España,* vol. V, p. 201–388. Full title: Relacion del descubrimiento y conquista de los reinos del Perú, y del gobierno y órden que los naturales tenian, y tesoros que en ella se hallaron: y de las demas cosas que en él han subcedido hasta el dia de la fecha. Hecha por Pedro Pizarro conquistador y poblador destos dichos reinos y vecino de la ciudad de Arequipa. Año. 1571. A second edition of Pedro Pizarro, reprinted from the Navarrete edition, appeared in the *Colección de libros y documentos referentes a la historia del Perú,* vol. 6, Lima, 1917, with notes by H. H. Urteaga, and a biography of Pedro Pizarro by C. A. Romero; in the same volume can be found the *Relación de los hechos de los españoles en el Perú desde su descubrimiento hasta la muerte del Marqués Francisco Pizarro,* por el padre fray Pedro Ruiz Naharro de la Orden de la Merced. An English translation of Pedro Pizarro's relation, by P. A. Means, was published by The Cortes Society, New York, 1921.

(T) Pedro SANCHO de la Hoz. Re-translated by ICAZBALCETA.
Relación para S. M. de lo sucedido en la conquista. . .
Mexico. 1849.

Remarks. (T) is a Spanish translation of the Ramusio translation (P 6); it was made by Joaquín García Icazbalceta, and first published as an addition to his translation of Prescott's *Conquest of Peru;* a second edition of this Spanish re-translation appeared in the complete works of Icazbalceta, vol. 8, p. 299–423, in the *Biblioteca de autores mexicanos,* Mexico, 1898. It was reprinted, with notes by H. H. Urteaga and a biography by C. A. Romero, in the *Colección de libros y documentos referentes a la historia del Perú,* vol. 5, p. 122–224, Lima, 1917. An English translation—from the Spanish of Icazbalecta, not from the Italian of Ramusio—was made by P. A. Means, and published by The Cortes Society, New York, 1917.

(U) Oviedo, author. José Amador de Los Rios, editor.
Historia general y natural de las Indias.
Madrid. Real Academia de la Historia. 1851–55. 4*to.* 4 vols.

Remarks. First complete edition of the three parts of the work; the first part was published in 1535 (J) and reprinted in 1547 (N), (O). The 12 books of part three, or books 39–50 of the *Historia general y natural,* were published for the first time in vol. 4, in 1855. The conquest of Peru is treated in books 46–49. Chapters 1–14 of book 46 are based on the *Verdadera relacion* of Xerez. Chapter 14 consists of a report on the execution of Atahuallpa, and ends thus: “«Acabóse esta relaçion por Françisco de Xerez, escriptor della por mandado del gobernador, en el pueblo de Caxamalca destos reynos de la Nueva Castilla, en postrero de julio de mill é quinientos é treynta é tres años. —Françisco de Xerez.» Diçe el choronista que á Françisco de Xerez se le olvidó de deçir en su relaçion que no fué él solo el que essa su relaçion ordenó. É la original que yo tengo firmada de su nombre no proçede con buen estilo; pero arrimándome yo á lo quél escribió é á lo que he podido inquerir de la prission é muerte injusta de Atabaliba, he escripto con toda limpieça de mi pluma aquello ques dicho, é lo demás quél calló ó no lo supo, é lo que ha subçedido despues quél se vino á España.” Chapters 11 and 12 give the report of Estete; the difference between the reports in (C) and (U) is such, that at least one of them must be considered as an edition digressing in important details from the original diary. The following passage from the Xerez edition of Estete, C3v2 in (C): “Otro dia domingo a treynta d(e) Enero partio el capita(n) d(e)ste pueblo: y sin salir d(e) arboledas y pueblos llego a Pachalcami: q(ue) es el pueblo do(n)de esta la mezquita. A medio camino esta otro pueblo gra(n)de do(n)de el capita(n) comio” should be compared with the corresponding commented quotation from Estete, as given by Oviedo, (U), p. 191: “Otro dia, domingo treynta del dicho mes de enero (pero en esta cuenta destos dias me paresçe questa relaçion anda errada, salvo si en aquella tierra enero no trae mas dias que acá, é no me maravillo, porque aun en el oro traian más errada la cuenta, como se dirá en su lugar; en fin, yo digo lo questa relaçion diçe) queste dicho treynta de enero de mill é quinientos é treynta é tres salió el capitan deste pueblo de Pachacama, que es donde está la mezquita ó templo del diablo, é al medio camino está otro pueblo grande, donde el dicho capitan comió, que se diçe *Armatambo,* y el señor dél se llama por su nombre Trianchumbi." At the end of Chapter 12, Oviedo adds: "É con esto se dá fin á la relaçion quel veedor Miguel Estete escribió del viaje en que fué é se halló con el dicho capitan Hernando Piçarro, assi como en este capítulo y en el preçedente se ha dicho: y en la verdad á este hidalgo que lo escribió yo le conozco, é tengo por çierto quanto diçe; pero quisiera yo que supiera él deçir en qué altura é grados están los pueblos é lugares, que deste camino se han nombrado." Book 46 contains also, in Chapter 15, the famous letter of Hernando Pizarro, "Á los magníficos señores, los señores oydores de la Audiençia Real de Su Magestad, que residen en la cibdad de Sancto Domingo," "fecha en esta villa de Sancta Maria del Puerto á veynte é tres dias de noviembre de mill é quinientos é treynta é tres años." The testimony of Diego de Molina, another witness of the events chronicled in (B) and (C), is recorded in chapter 16 of book 46; Molina is mentioned in Hernando Pizarro's letter; Oviedo interviewed him in Santo Domingo, in December, 1533.

(V) Miguel de ESTETE, author. Carlos M. LARREA, editor.
El descubrimiento y la conquista del Peru.
Quito, Ecuador. 1918.

Remarks. First edition, with introduction, notes, and 12 photofacsimile plates, edición especial del artículo publicado en el "*Boletín de la Sociedad Ecuatoriana de Estudios Históricos Americanos,*" vol. 1, No. 3. The New York Public Library has a MS, "*Miscelanea del Peru.* Papers relating to the discovery and conquest of the country, the Indians, etc. Six transcripts from the Simancas archives and elsewhere. (1800?)"; the volume was purchased from O. Rich; this MS was used by Prescott in his *History of Peru.* The first of the six transcripts consists of 24 leaves and contains the same report as (V). A note, not by the copyist, introduces it as follows, recto of leaf 1: "Relacion del descubrimiento y conquista del Perú, escrita por uno de los conquistadores. Existe al parecer original pero imperfecta en el Archivo general de Ind(ia)s de Sev(ill)a entre los papeles traidos del de Simancas legato 4°. de los rotulados: Relaciones y descripciones." At the end, after the last words, ". . . Governador, y Inga à vn llano," is the following note, written by the same hand as the title-note: "Hasta aqui llega el original q(u)e es un quaderno en folio de 12 pl. Hay alg(unas) correcciones de letra muy semejante, pero dif(erent)e tinta, y de esta hai al principio las sig(uien)tes palabras: De Miguel destete: sin duda falta otro quaderno: la letra parece de los años 30–40." Marginal notes, by the same hand, prove that the N. Y. P. L. transcript has been collated with its original in Spain; it can therefore be assumed that they were added before the transcript was used by Prescott. The final note of the N. Y. P. L. transcript was for some reason disregarded by Prescott, because in the footnote 7 of chapter VI of volume I of his *Conquest of Peru* he mentions the "Relacion del Primer. Descub., MS." as the work of an anonymous author, and adds: "Both the last-cited author and Miguel Estete, the royal *veedor* or inspector, accompanied Hernando Pizarro on this expedition, and, of course, were eyewitnesses, like himself, of what they relate. Estete's narrative is incorporated by the secretary Xerez in his own." The title of the MS published by Larrea is *N[oticia] del Peru,* and appears in the left-hand upper corner of the recto of the first leaf. The report differs considerably from the diary of Estete incorporated in Xerez, (C), and in Oviedo, (U).

(W) Miguel de ESTETE, author. Horacio H. URTEAGA, editor.
Relación del descubrimiento y conquista del Perú.
Lima. Sanmarti y Ca. 1924.

Remarks. Colección de libros y documentos referentes a la historia del Perú, 2a. serie, tomo 8, p. XV–XXX, 3–71. The text of the report, reprinted from (V), under the title "Noticia del Perú de Miguel de Estete (de los papeles del Arca de Santa Cruz)", occupies p. 3–56; the notes of C. M. Larrea are reprinted on p. 57–71; the footnotes are by H. H. Urteaga; the biographical note by Domingo Angulo. The title appears in the Indice as follows: "Relación que del descubrimiento y conquista del Perú hizo el capitán Miguel de Estete al Supremo Consejo de las Indias."

(X) ANONYMOUS author. Joseph H. SINCLAIR, translator.
The conquest of Peru.
New York. The New York Public Library. 1929.

Remarks. A facsimile reproduction of (B), preceded by an introduction (one page), and followed by an English translation; a bibliography (three pages) and two maps are added. For further particulars, see my detailed review of (X) in *Isis*, vol. 14, p. 244–250, 1930. The facsimile reproduction of (B) should be used with caution, because damaged letters have been tampered with, the results being, e. g., "d(e)o(n)de ouiu os" for "do(n)de ouimos" (2r7), "aqnellos cacioues" for "aquellos caciques" (2r29), "onimos" for "ouimos" (3r10), "quisies o que" for "quisiesse, que" (3v28), "etros" for "otros" (6v21), "o(n) squells" for "q(ue) aquella" (6v24), "lo" for "le" (7r4), "aconsejaren" for "aconsejaron" (7r35), "seuella" for "aquella" (7v6), etc. The translation is good, but there are several serious misreadings, e. g., "vna puerta" for "vn puerto" (3v6), "herbage" for "herrage" (5v37), "casa" for "caxa" (7r43), etc.; the last quoted error, "a great house filled with golden vases," has been made by the translator independently from "vna gran casa piena di vasi d'oro," because he did not consult the Italian version of (B). His acquaintance with the French edition, (K), is very superficial.

La conquista del Peru.

llamada la nueua Castilla. La qual tierra por diuina voluntad fue marauillosamente conquistada en la felicissima ventura del Emperador y Rey nuestro señor: y por la prudencia y esfuerço del muy magnifico y valeroso cauallero el Capitan Franciso piçarro Gouernador y adelantado de la nueua castilla, y de su hermano Hernando piçarro, y de sus animosos capitanes y fieles y esforçados compañeros, que con el se hallaron.

* * *

2 r Año de mil y quinientos y treynta y vno en el mes de hebrero nos embarcamos en el puerto de Panama que es en tierra firme dozientos y cincuenta hombres, los ochenta de cauallo Lleuamos por capitan al muy magnifico y esforçado cauallero Francisco piçarro. Nauegando por el mar del sur quinze dias, fuemos a desembarcar a la baia que agora se llama de sant Matheo. y saltando en tierra fuemos cien leguas conquistando algunos pueblos. y fuimos a vn pueblo llamado Coaque donde ouimos algun oro. En esta pro-

Oviedo. *1526. Fol. 10v:*
. . . desde la mar del norte hasta la mar del sur . . . no ay de costa a costa por tierra, mas de .xviij. o veynte leguas de traues.

Oviedo. *1526. Fol. 12v:*
Esta la costa del Norte enel dicho Golpho de Uraba, y enel puerto del Darien, adonde desde España van los Nauios en siete grados y medio: . . .

Xerez *A2r2:*
y caminaron hasta llegar a vn gran pueblo que se dize Coaque: al qual saltearon porque no se alçasse como los otros pueblos: y alli tomaron quinze mil pesos de oro y mil y quinientos marcos de plata y muchas piedras de esmeraldas: que por el presente no fueron conoscidas ni tenidas por piedras de valor: por esta causa los Españoles las dauan y rescatauan con los indios por ropa y otras cosas que los indios les dauan por ellas.

LIBRO VLTIMO DEL SVMMARIO

de le cose de le Indie occidentali, doue si narra di tutto quello ch'è stato fatto nel trouar la prouincia de Peru, ouer del Cusco, chiamata hoggi nuoua Castiglia, dalli capitani del Imperatore.

Si come nelli precedenti libri s'è veduto chiaramente, nella terra ferma delle Indie occidentali, gradi sette sopra la linea de l'equinottiale, nelle prouincie de Esquegua & Vrraca è la terra tanto stretta che da mar à mar non è piu di .xviii. in .xx. leghe, che à miglia quattro per lega sariano circa .lxxx. miglia. di modo che chi stesse in su la piu alta sommita delle montagne de Esquegua, & guardasse verso tramontana vederebbe il mar che si chiama del Nort. & voltandosi à l'opposito verso mezzo di, vederebbe il mar del Sur. nellequali parti son stati fatti habitar dal signor Pedrarias capitano del Imperator duoi porti molto commodi nella nauigatione di quelli mari. cioè nel mar del Nort qual vien verso Spagna, vna citta con vn porto detto il Nome de Dio. Et ne l'altro mar del Sur Panama Citta & porto antico de li Indiani: ma al presente pieno di christiani con il suo episcopo.[1] *In questa citta adunque trouandosi il valoroso Caualliero Francesco Pizarro capitano con suo fratello il Signor Hernando Pizarro desiderosi di scoprir cose nuoue in questo mare del Sur cioe di mezzo di, fabricorono alcuni nauilii, hauendoui abondantia grandissima di legnami, & altre cose necessarie a tale impresa. Et pensorono d'andar tanto nauigando che trouassero l'isole delle Moluche doue nascono tutte le spetierie: ma la fortuna fu loro molto piu fauoreuole di quel che pensorono, perche auanti trouorono tanti ori & argenti, che dimenticorono d'andar a trouar dette Moluche, & fu il viaggio in questo modo secondo che da persona prudente & pratica che vi fu presente breuemente è descritto.* Nel anno .1531. del mese di Febraio noi imbarchammo nel porto di Panama, ilquale è in terra ferma *de le Indie gradi sette sopra l'equinottiale, nel mar del Sur, cioe verso mezzo di, & fummo* .250. huomini à pie & .80. à cauallo sotto il Capitano & valoroso caualllier Francesco pizzarro, & nauigando per il detto mare, quindici giorni, dismontammo in vna spiaggia che al presente si chiama san Mattheo. & dismontati in terra 2 v andammo circa cento leghe *che a quattro miglia per legha sono .400. miglia,* conquistando sempre molti luoghi *habitati da Indiani:* & arriuammo à vna terra chiamata Coaque, qual è sotto la linea equinot-

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[1] 1535: episco. 1556, 1565, 1606: Vescouo.

uincia adolescio mucha gente: porque la tierra es mal sana porque esta debaxo de la linea equinocial. De alli passamos a vna ysla llamada la Pugna alli estouimos quatro o cinco meses: donde murieron ocho o diez de nosotros. De alli atrauessamos y fuimos a la ciudad de Tumbez: alli estouimos dos o tres meses. De alli fuimos a vn pueblo llamado Tangarara: adonde hizimos vna poblacion que llamamos sant Miguel. Alli tuuimos noticia de vn gran señor llamado Atabalipa: elqual tenia guerra con vn su hermano mayor llamado el Cozco: al qual auian desbaratado ciertos capitanes del Atabalipa: y el yua con gran exercito despues de sus capitanes a la sazon que llego al señor gouernador Francisco piçarro con sesenta de cauallo y nouenta de pie: porque los demas quedauan en el pueblo de sant Miguel. Quando Atabalipa supo que yuan los christianos: embio vn capitan a espiar que gente eramos. Este capitan vino a nuestro real desfraçado como indio de baxa suerte: y no oso con toda su gente dar en nosotros: mas luego se boluio a hazer relacion a su señor: y le dixo que le diesse mas gente: y que bolueria a dar en los christianos. el cacique le respondio (segun despues nos dixo) que mas a su saluo tomaria a los Christianos quando ellos llegassen a donde el estaua. Sabiendo el gouernador que este cacique andaua conquistando aquella tierra con mucho numero de gente: determino de yr en busca

XEREZ *A2v1:*

Asi anduuo el gouernador con la gente española hasta llegar a vna ysla que se dezia la pugna, a la qual los christianos llamaron la ysla de Santiago que esta dos leguas de la tierra firme y por ser esta ysla bien poblada y rica y abundosa de mantenimientos passo el gouernador a ella en los dos nauios y en balsas de maderos que los indios tienen: en las quales passaron los cauallos. ¶ *El gouernador fue recebido en esta ysla por el cacique señor della con mucha alegria y buen recebimiento assi de mantenimientos que le sacaron al camino como de diuersos instrumentos musicos que los naturales tienen para su recreacion Esta ysla tiene quinze leguas en circuyto: es fertil y bien poblada.*

XEREZ *B1r1:*

. . . *hasta que apremiados della desampararon la ysla, y se passaron a tierra firme: y por ser la ysla tan poblada, abundosa, y rica:* . . . *En tres dias arribaron los nauios a la playa de Tumbez.*

tiale, doue trouammo qualche poco d'oro *& qualche pietra di Smeraldo.* In questa terra si amalo assai delli nostri, & quindi passammo ad vna Isola allhora chiamata la Pugna, *hoggi san Iacopo,*[1] *due leghe lontane da terra ferma, di circuito di leghe quindici, molto populata & ben cultiuata, & per questo abondantissima di vettouaglie: & il Cacique de l'isola volendoci far piacere ci mandaua de le vettouaglie, & auanti di quelli che le portauano, erano persone che sonauano di diuersi instrumenti.* nellaqual stemmo cinque o sei mesi doue morirono otto o dieci de nostri. Di li *con nauilii* attrauersammo & arriuammo *in terra ferma* alla citta di Tumbez, doue stemmo tre mesi, & di quindi andammo ad vna terra detta Tangarara: nellaquale facemmo vn ridotto per habitar qual chiamammo san Michele. nelqual luogo cominciammo hauer noticia d'vn gran *Cacique, ouer* signor nominato Atabalipa, & d'vn suo fratello maggior[2] chiamato Cusco, con ilqual faceua guerra & dalli capitani d'Atabalipa, fu seguitato con grande essercito, *tanto che fu fatto prigione.*[3] In questo tempo che costoro guerreggiauano, arriuo il signor Francesco Pizarro con .60. caualli & 90. fanti. perche li altri restorono nel ridotto di san Michele.[4] Quando Atabalipa intese che veniuan li christiani, mando vn capitano a spiar che gente erauamo. questo capitano venne verso il nostro campo, & non li basto l'animo con le genti che haueua combatter con esso noi: ma subito ritorno indietro[5] a dar risposta al suo Signore, con dirgli che se gli desse piu gente che ritorneria a combattere. Il Cacique gli rispose, (secondo che dipoi ci fu detto) che piu sicuramente prenderia li christiani quando loro arriuassero doue lui era. Intendendo il *signor* Gouernator *Francesco Pizarro* che questo Cacique andaua acquistando quel paese con gran numero di gente: determino di andarlo a trouar con quella

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[1] 1556: sant'Iago, doue leghe. 1565, 1606: sant'Iago, due leghe.

[2] 1556, 1565, 1606: fratello chiamato Cusco. 1545: frere cousin nommé Cusco.

[3] 1545: fut pris prisonnier par vn de ses capitaines.

[4] 1545: en nostre fort sainct Michel.

[5] 1556, 1565, 1606: ritornò indreto.

del con la poca gente que lleuaua: que seriamos todos ciento y cincuenta: en que yrian quasi sesenta de cauallo. Assi partimos en busca deste cacique: que nos amenazauan que el nos vernia a buscar: y el gouernador quiso yr a buscar a el: en vn pueblo que se dize Piura hallo el gouernador a vn capitan hermano suyo: a quien hauia embiado adelante con quarenta de pie y de cauallo: y del supo como todos aquellos caciques le amenazauan con atabalipa. alli se informo el gouernador de los indios: y le dixeron que este cacique estaua en vn pueblo llamado Caxamalca: y que alli lo esperaua con mucha gente. preguntando por el camino, y de la manera que era poblado, le dixeron los indios y vna india que trayamos que en aquel camino auia muchos despoblados: en que auia vna sierra muy fria de cinco jornadas: y en las dos no auia agua: El señor gouernador partio con su gente: siete dellos se boluieron al pueblo con temor de los malos caminos y poca agua Con el gran desseo que el gouernador y los de su compañia tienen de seruir a su magestad, no rehusaron el trabajo del camino: y fueron a vn pueblo que estaua dos leguas de alli, que era repartimiento del señor capitan Hernando piçarro: el qual se auia adelantado quatro dias antes por apaziguar aquel cacique: quando el gouernador llego, supo que tres jornadas de alli estaua vn pueblo que se dezia Caxas: en elqual estauan aposentados muchos indios de guerra que tenian recogidos muchos tributos con que Atabalipa bastecia su real. Hernando piçarro quisiera yr alla: y el gouernador no le quiso dar licencia: y embio al capitan Hernando de soto con mucho recelo de la poca gente que tenian: y diole cincuenta o sesenta hombres. y dixo le que el le esperaria en vn pueblo que se dezia Caran: y que alli le viniesse a ver: o embiasse dentro de diez dias. El señor capitan Hernando de soto se partio con aquella gente al dicho pueblo de Caxas: y llegando cerca supieron que la
2 v gente de guerra auia estado alli sobre vna sierra esperandolos, y se auian quitado de alli. Llegaron al pueblo que era

poca gente che hauea: che erauamo in tutto .150. tra liquali erano circa .60. à cauallo, & cosi andammo à trouar questo Cacique, ilquale minacciaua di venire ad assaltarci. onde il gouernator volse andar a trouar lui. Et giunti ad vn loco ditto Piura il gouernator trouo vn capitano suo fratello qual hauea mandato auanti con .40. tra fanti & caualli, & da lui seppe come tutti quelli Caciqui *ouer signori* lo minacciauano con Atabalipa Qui si informo il gouernator dalli Indiani, 3 r daliquali intese come questo Cacique *Atabalipa* staua in vna terra chiamata Caxamalca doue lo aspettaua con molta gente, & dimandando del camino, & come il paese era habitato intese da quelli & da vna Indiana che menauamo con esso noi, che in quel camino erano assai *luoghi* dishabitati, & che vi era vna montagna, nel passar della quale *per esser molto alta*, si sentiua gran freddo per cinque giornate, & che duoi giorni non trouarremo acqua. *nientedimeno* il signor gouernator si parti con le sue genti *molto allegri*, ma sette de li suoi *fanti* se ne ritornorono al ridotto, hauendo paura del camino per esser cattiuo & con poca acqua. ma il gran desiderio del *signor* gouernator & della sua compagnia che haueuano di seruir la *Cesarea* maiesta, fece che non ricusorno a trauaglio o a faticha che potessino hauere. Et andorono ad vn luogho lontano da quello due leghe, doue quattro giorni auanti era arriuato il signor capitano Hernando pizarro per pacificar quel Cacique. quando il gouernator arriuo a questo luogho, intese che tre giornate lontano da quel luogo era vna terra detta Caxas nellaquale erano alloggiati molti Indiani, huomini da guerra, & haueuano accumulati molti tributi, con liquali Atabalipa forniua il suo campo. Hernando Pizarro volse andarlo a trouare: ma il Gouernator non gli volse dar licentia, & mando Hernando di Soto con molto sospetto per la poca gente che haueuano. & gli dette .50. ouer .60. huomini con dirli che lo aspetteria in vn loco che si chiama Caran,[1] & che lo venisse a trouare o gli mandasse alcun fra dieci giorni. il capitano Hernando de Soto si parti con la detta gente verso il detto luogo de Caxas. Et arriuandogli appresso, seppe che la gente di guerra era stata sopra vna montagna aspettandoli, donde si erano partiti. arriuorono costoro al luogho ch'era grande, & in alcune case

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[1] 1545: Carez.

grande: y en vnas casas muy altas hallaron mucho mayz: y calçado, otras estauan llenas de lana y mas de quinientas mugeres que no hazia otra cosa sino ropas y vino de mayz para la gente de guerra: en aquellas casas hauia mucho de aquel vino. Este pueblo estaua muy destruydo de la guerra que le auia dado Atabalica por los cerros auia muchos indios colgados porque no se le auian querido dar: porque todos estos pueblos estauan primero por el Cozco: y le tenian por señor, y le pagauan tributo. El capitan embio a llamar al cacique de aquel pueblo: y luego vino querando se mucho de Atabalipa de como los auia destruydo y muerto mucha gente, que de diez o doze mil indios que tenia, no le auia dexado mas de tres mil: y que aquellos dias passados estaua gente de guerra en aquel pueblo: y como supieron que venian los christianos, que por temor dellos se hauian ydo. El señor capitan les dixo que estuuiessen de paz con los christianos: y fuessen vassallos del Emperador: y que no tuuiessen miedo de Atabalipa. El cacique se holgo mucho: y luego abrio vna casa de aquellas que estaua cerrada y puesta guarda por Atabalipa: y saco della quatro o cinco mugeres, y diolas al capitan, para que siruiessen a los christianos en

XEREZ *B3v1:*

. . . *y ropas de lana de la tierra que de Caxas truxeron* (*que es cosa de ver en España la obra y primeza della: que mas se juzgara ser de seda que de lana: con muchas lauores y figuras de oro de martillo muy bien assentado*[1] *en la ropa*)

XEREZ *B3v1/2:*

Por este camino toda la gente tiene vna mesma manera de biuir. Las mugeres visten vna ropa larga que arrastra por el suelo como habito de mugeres de Castilla. Los hombres traen vnas camisas cortas es gente suzia: comen carne y pescado todo crudo el mayz comen cozido y tostado. Tienen otras suziedads de sacrificios y mezquitas: a las quales tienen en veneracion: todo lo mejor de sus haziendas ofrescen en ellas. Sacrifican cada mes a sus propios naturales e hijos: y con la sangre dellos vntan las caras a los ydolos y las puertas a las mezquitas: y echan della encima de las sepolturas de los muertos. y los mesmos de quien hazen sacrificio se dan de voluntad a la muerte riendo y baylando y cantando: y ellos la piden despues que estan hartos de beuer ante que les corten las cabeças. tambien sacrifican ouejas.

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[1] Original: *aensstado.*

molto alte trouorono gran quantita de mahiz, *ch'è vn grano como ceci*[1] *bianco, delquale fanno pane,* & molte scarpe, & le altre case erano piene di lana, & trouorono piu di cinquanta donne, che non faceuano altro che veste, & similmente vino[2] di mahiz, *cioe di quel grano* per li huomini da guerra. delqual vino per le case non era poca quantita. *le veste che faceuano erano di tale fineza che noi pensauamo che fussino di seta, lauorate con figure d'oro tirato o battuto, benissimo commesso. le donne vestono veste lunghe, talmente che le strascinano per terra, li huomini portan certe camicie corte senza maniche, & son brutti. il mangiar loro, e quasi di cose crude, eccetto il mahiz che cuocono. sacrificono ogni mese le piu care cose che habbino, & alcuna volta li proprii figliuoli ad* 3 v *vno Idolo, il volto delquale bagnano con il sangue, & anchora le porte delle moschee.* Questa terra era molto destrutta per la guerra che gli hauea fatto Atabalipa, & sopra[3] li arbori erano molti Indiani ascosi: liquali non se gli erano voluti dare. tutti questi popoli auanti erano sotto il Cusco, & quello teneuano per signore, & pagauangli tributo. Il Capitano allhora mando a chiamar il Cacique di quel luogho, qual subito venne, dolendosi molto fortemente di Atabalipa, che cosi gli hauea destrutta la terra, & mortogli molta gente che di .x. o .xii. milia Indiani che hauea, non gli eran rimasti piu che tre milia. Et che ne li giorni passati era la gente da guerra in quel luogo, & come seppono che vi veniuano li christiani, per paura di quelli se ne erano partiti. *Allhora* il signor Capitano disse a tutti che stessero in buona pace con li christiani, & fussero vassalli dello Imperatore, & che non hauessero paura d'Atabalipa. Il Cacique hebbe molto piacere di tal cosa. Et subito aperse vna casa di quelle ch'erano serrate, & poste in guardia per Atabalipa, & cauo di quella quattro o cinque donne, & dettele al Capitano, perche seruissero alli christiani in apparechiarli

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[1] 1545: trouuerent du mahiz à planté (qui est vn grain blanc de la forme de chiche duquel ilz font leur pain).

[2] 1545: plus de cinquante dames qui ne faisoient que faire robbes & vins de leur grain de mahiz pour la munition du camp.

[3] 1545: parmy les bois estoient cachez grand nombre d'Indoys.

guisar de comer por los caminos. oro dixo que no lo tenia: porque todo se lo auia tomado Atabalipa: todauia dio quatro o cinco tejuelos de oro de minas. Estando en esto vino vn capitan de Atabalipa: el cacique huuo gran temor: y se leuanto en pie: que no oso estar assentado delante del mas el señor Hernando de soto lo hizo assentar cerca de si. Este capitan traya vn presente para los christianos de parte de Atabalipa. El presente era todo de patos dessollados: que significaua que assi hauian de dessollar a los christianos: y mas truxo dos fortalezas muy fuertes hechas de barro: diziendo que otras auia adelante como aquellas. El capitan Hernando de soto partio de alli, lleuando con sigo aquel capitan de Atabalipa: y llego donde estaua el señor gouernador: elqual huuo mucho plazer de ver aquel capitan de Atabalipa: y diole vna camisa muy rica, y dos copas de vidro para que las lleuasse a su señor, y le dixesse, que el era su amigo, y que holgaria mucho de verle: y que si tenia guerra con alguno que el le ayudaria. El capitan de Atabalipa se boluio a donde su señor estaua. De alli a dos dias se partio[1] el governador, para yr a ver se con Atabalipa: y hallaua por el camino destruydos los mas de los pueblos y los caciques ausentados: que todos estauan con su señor. Yendo por aquel camino que era la mayor parte tapiado de las dos partes y arboles que hazian sombra, de dos en dos

XEREZ *B3r2:*

Con el capitan vino vn indio principal con otros algunos. Dixo el capitan que aquel indio auia venido con cierto presente para el gouernador. Este mensagero dixo al gouernador que su señor atabaliba le embiaua desde caxamalca para le traer aquel presente que eran dos fortalezas a manera de fuente figuradas en piedra con que beua: y dos cargas de patos secos dessollados para que hechos poluos se sahume con ellos. porque assi se vsa entre los señores de su tierra: y que le embia a dezir que el tiene voluntad de ser su amigo: y esperalle de paz en Caxamalca.

XEREZ *B3r2:*

Passa por aquellos dos pueblos vn camino ancho hecho a mano que atrauiessa toda aquella tierra, y viene desde el Cuzco hasta Guito que ay mas de trezientas leguas. va llano: y por la sierra bien labrado. es tan ancho que seys de cauallo pueden yr por el a la par sin llegar vno a otro. Van por el camino caños de agua traydos de otra parte de donde los caminantes beuen. A cada jornada ay vna casa a manera de venta donde se aposentan los que van y vienen.

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[1] Original: pario.

da mangiar per il camino. De l'oro dissero che non ne haueano, perche tutto lo hauea tolto Atabalipa, pur gli dette quattro o cinque tegole, *che sono piastre tonde* d'oro di minera. In questo mezzo venne vn Capitano di Atabalipa. Il Cacique hebbe gran paura, & leuossi in piede non hauendo ardimento di star a sedere auanti quello. Ma il signor Hernando di Soto se lo fece sedere appresso. Questo Capitan portaua vno presente alli christiani da parte di Atabalipa. Il presente era due *fontane di pietra fatte a modo di* fortezza, *per bere,* & due some di vccelli, che pareuano oche scorticati secchi, *deliquali in quel paese fanno gran conto: perche ne fanno poluere, & con quella si profumano.* Il Capitan Hernando di Soto si parti di quel luogho, & meno seco quel Capitan de Atabalipa, & ando a trouare il Gouernatore, qual hebbe molto piacer di veder quel capitan, & dettegli vna camicia molto ricca, & due coppe di vetro: lequal presentassi al suo signore, & gli dicesse che egli era suo amico, & che haueria piacer di vederlo, & che se hauea guerra con alcuno, che lo aiutarebbe. partissi il Capitano alla volta del suo signore, & dapo duoi giorni si parti il Gouernator per andarsi a incontrar con Atabalipa. Et trouo per il camino destrutto quasi tutto il paese, & i Caciqui fuggiti, che tutti erano ridotti con il suo signore. & andando per quel camino ch'era la maggior parte fatto con argini di terra da ogni banda, & pien di arbori che faceuano ombra di due 4 r in due leghe,[1] trouauano alloggiamenti *con alcuni condotti di aqque per commodita de li viandanti.* Et arriuando appresso alla montagna

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[1] 1545: La plusgrand partie du chemin estoit d'ung costé maconnée de leuée de terre & toute vmbragée d'arbres, & de deux en deux lieues lon trouuoit certains hebergemens auec quelques conduictz d'eau pour la necessité des passans. 1556, 1565, 1606: ombra di due in due leghe.

leguas hallauamos aposento. Llegando cerca de la sierra, Hernando piçarro y Hernando de soto se adelantaron con alguna gente: y passaron vn rio grande nadando: por que nos auian dicho que en vn pueblo adelante auia mucha riqueza: llegando al pueblo cerca de la noche hallamos la mayor parte de la gente escondida: y embiamos lo a dezir al gouernador. Otro dia por la mañana passo el rio el governador con toda la gente Antes de llegar al pueblo tomamos dos indios por saber nueuas del cacique Atabalipa: el capitan los mando atar a dos palos, porque tuuiessen temor. el vno dixo que no sabia de atabalipa: mas que el otro auia pocos dias que auia dexado con el Atabalipa al cacique señor de aquel pueblo. del otro supimos que Atabalipa estaua en el llano de Caxamalca con mucha gente esperando a los christianos. y que muchos indios guardauan dos malos passos que auia en la sierra: y que tenian por vandera la camisa que el gouernador hauia embiado al cacique Atabalipa: y que el no sabia otra cosa mas de lo dicho. y con fuego ni con otra cosa nunca dixo mas desto. Los capitanes dixeron al gouernador lo que de los dos indios auian sabido. Despues de dos dias partimos de aquel pueblo: y el gouernador dexo aquel buen camino de tapias: y tomo otro que no era tan bueno: y llegando al pie de la sierra, hizo su retaguarda: y 3 r dexo con ella vn capitan que se llama Salzedo: porque es hombre de buen recaudo y ardid en la guerra. y el se patrio con los otros capitanes y gente mas suelta encomendandose a Dios y començo a subir por la sierra que era muy alta: en la subida della auia vna fortaleza cercada. El gouernador subio la sierra: aquel dia fue a dormir a vn pueblo vna legua de aquella fortaleza: a donde estaua vna casa fuerte de cal

XEREZ *B2v1:*

❡ *Tuuo noticia el gouernador que la via de Chincha y del Cuzco ay muchas y grandes poblaciones abundosas y ricas: y que doze o quinze jornadas deste pueblo esta vn valle poblado que se dize Caxamalca a donde reside Atabaliba, que es el mayor señor que al presente ay entre los naturales: al qual todos obedecen: y que lexos tierra de donde es natural ha venido conquistando: y como llego a la prouincia de Caxamalca (por ser tan rica y aplazible) assento en ella: y de alli va conquistando mas tierra.*

Hernando Pizarro & Hernando di Soto andorono auanti con alquanta gente, & passorono vn fiume grande notando perche haueuano inteso che in vn luogho auanti era molta ricchezza. Arriuati al luogo circa al far della notte trouammo la maggior parte della gente ascosa, & mandammo a dirlo al Gouernator. L'altro giorno la mattina passo il fiume il Gouernatore con tutta la gente. Et auanti che arriuassimo al luogo pigliamo duoi Indiani. liquali (per saper nuoua del Cacique Atabalipa). Il capitano ordino che fossero legati a duoi pali, perche hauessero paura. *nel domandarli* vno di quelli disse che non sapeua cosa alcuna di Atabalipa, ma che l'altro pochi giorni auanti hauea lassato con Atabalipa il Cacique di quel luogho. Da l'altro sapemmo che *nel camino che va alla prouincia del Cusco erano gran terre, & abondanti, & che* in vna *bellissima* valle *era vna citta chiamata* Caxamalca, *doue staua il gran Cacique Atabalipa figliuol del gran Cusco vechio, ilquale era il maggior signore che si trouasse fra li Indiani, & che quella Caxamalca era la maggior terra di quella prouincia del Cusco o uero Peru, & che* Atabalipa con molta gente aspettaua li christiani *in essa.* Et che molti Indiani guardauano duoi mali passi, ch'erano in su la montagna, & che portauan per bandiera la camicia che il Gouernator hauea mandato al Cacique Atabalipa. & che non sapeua altra cosa piu di quello hauea detto. ne con fuoco, ne con altro tormento disse piu di questo. I capitani dissero al Gouernatore quello che dalli duoi Indiani haueuano sentito. duoi giorni dapoi partimmo da quel luogo. Il Gouernator lascio quel buon camino fatto con li argini *sopradetti,* & prese altro camino che non era tanto buono, & arriuando a pie de la montagna, fece la sua retroguarda, & lascio con quella vn Capitan chiamato Salcedo: perche è huomo di buona guardia & ardito nella guerra. & lui si parti con altri capitani, & gente piu espedita raccomandandosi a Dio, & incomincio à montar su per la montagna ch'era molto alta, & nel montar trouo vna forte terra murata: *laqual passata al far della notte*[1] arriuo ad vn luogho vna legha dila da quella fortezza, doue eran case[2] fatte di calcina & pietre per alloggiar el

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[1] 1545: laquelle il passa & sur l'entrobscur de la nuyt arriua en vn lieu loing de là enuiron d'une lieue.

[2] 1545: quelques maisons.

y canto, donde solia aposentar el señor de aquella tierra: y la retaguarda vino a dormir a la fortaleza. El otro dia por la mañana quedaua otra sierra muy alta que estaua arriba del pueblo: y el camino yua por ella. Partimonos antes que saltesse el sol porque los indios no nos tomassen el camino que era muy mal passo, mando que fuessen todos ellos con su gente. Despues que lo ouimos subido tuuo el señor gouernador mucho plazer: porque pensauamos que nos lo hauian tomado los indios: como el indio que quemamos auia dicho. y alli espero el gouernador a su retaguarda porque fuessen todos juntos: porque nos parecio que auiamos subido lo mas alto de la sierra fria: y luego la retaguarda llego aquella noche vinieron dos indios con diez, o doze ouejas por mandado del Atabalipa y las dieron al gouernador. el les dio muchas cosas y los embio. En aquella sierra tardamos cinco dias. y vna jornada antes que allegassemos al real del Atabalipa vino de su parte vn mensagero: y truxo en presente muchas ouejas cozidas y pan de mayz y cantaros con chicha. Y como el gouernador hauia embiado vn indio del camino. era este indio cacique de los pueblos en los quales los christianos estauan repartidos: y eran grandes amigos de los christianos. este cacique fue al real de Atabalipa y sus guardas no le dexaron llegar alla: antes le preguntaron que de donde venia el mensagero de los diablos? que por tanta tierra auian venido, y no auia quien los matasse. el cacique les dixo que le dexassen yr a hablar con el Atabalipa: porque quando algun mensagero yua a los christianos, ellos le hazian mucha honra. y ellos no le dexaron passar adelante: aquella noche vino a dormir donde el gouernador auia llegado con su gente: y auia auisado al gouernador que ninguna cosa de comer que el Atabalipa embiasse, no la comiessemos: y assi fue hecho: que toda la vianda que el Atabalipa embio, fue dada a los indios que lleuauan las cargas. Antes de hora de bisperas llegamos a vista del pueblo que es muy grande: y hallamos muchos pastores y carneros del real de Atabalipa y vimos abaxo del pueblo cerca de

Signor di quella terra, & la retroguarda arriuo la sera alla fortezza. il
sequente giorno restaua vna montagna molto alta ch'era sopra quello
luogho, & il camino era per quella: partimoci auanti al leuar del
sole, accioche li Indiani non ci impedissero la strada, doue era vn passo 4 v
molto cattiuo: alqual fu ordinato che fossero tutti *li capitani*[1] con
le sue genti. Dapoi che hauemmo montato hebbe il signor Gouernator
molto piacer: perche pensaua che li Indiani lo hauessino preso
come l'indiano che tormentamo con il fuoco ci haueua detto. Et
quiui aspettò el gouernator la retroguardia, accioche andassimo tutti
vniti, parendoci hauer montato il piu alto de la montagna fredda, &
subito la retroguardia arriuo: in quella notte vennero[2] duoi Indiani
con dieci ouero dodici pecore per comandamento de Atabalipa, &
quelle detteno al Gouernator, ilqual li dette molte cose, & lo rimando.
in quella montagna dimorammo cinque giorni: *dapoi partimo alla
volta del campo d'Atabalipa*: & vn giorno auanti che arriuassimo al
campo, venne da sua parte vn messo, & porto vn presente di molte
pecore cotte & pan de mahiz & vasi con *vino detto*[3] chicha. & hauendo
il Gouernator mandato vn Indiano: ilqual era Cacique de luoghi
doue erauamo alloggiati, grande amico delli christiani, questo Cacique
ando fino al campo di Atabalipa: le guardie delquale non lo lascioron
passare, anzi lo domandorno donde veniua il messaggier di Diauoli,
ch'erano venuti per tanto camino, & non trouauano chi gli amazzasse.
il Cacique gli prego che lo lasciassino andar a parlar con Atabalipa.
perche quando alcun nuntio andaua alli christiani gli era fatto molto
honore. loro per questo non lo lasciorono andar auanti, & quella notte
torno a dormir doue il gouernator era arriuato con la sua gente, & fece
auisato il gouernatore che nissuna cosa da mangiar che Atabalipa
mandasse: mangiassero, & cosi fu fatto. che tutta la viuanda che
Atabalipa mando fu data alli Indiani che portauano le bagaglie.
Auanti l'hora di vespro arriuammo à vista de la terra, che è molto
grande, & trouammo molti pastori, & bechari del campo de Atabalipa.

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[1] 1545: Auquel lieu fut ordonné que toute la compagnée se trouuast vnye.

[2] Original: venneno.

[3] 1545: vin de chiche.

vna legua vna casa cercada de arboles: al derredor de aquella casa a cada parte estaua cubierto de toldos blancos mas de media legua: alli era el real donde el Atabalipa nos estaua esperando en el campo. Assi llegamos al pueblo: y

XEREZ *B5v2/B6r1:*

Este pueblo que es el principal deste valle esta assentado en la halda de vna sierra: tiene vna legua de tierra llana. passan por este valle dos rios este valle va llano mucha tierra poblada de vna parte y otra cercado de sierras. Este pueblo es de dos mil vezinos: a la entrada del ay dos puentes porque por alli passan dos rios. La plaça es mayor que ninguna de España toda cercada con dos puertas que salen a las calles del pueblo. Las casas della son de mas de dozientos passos en largo. son muy bien hechas cercadas de tapias fuertes de altura de tres estados. las paredes y el techo cubierto de paja y madera assentada sobre las paredes: estan dentro destas casas vnos aposentos repartidos en ocho quartos muy mejor hechos que ninguno de los otros. Las paredes dellos son de piedra de canteria muy bien labradas, y cercados estos aposentos por si con su cerca de canteria y sus puertas y dentro en los patios sus pilas de agua trayda de otra parte por caños para el seruicio destas casas. por la delantera desta plaça a la parte del campo esta encorporada en la plaça vna fortaleza de piedra con vna escalera de canteria por donde suben de la plaça a la fortaleza por la delantera della a la parte del campo esta otra puerta falsa pequeña con otra escalera angosta sin salir de la cerca de la plaça. Sobre este pueblo en la ladera de la sierra a donde comiençan las casas del esta otra fortaleza assentada en vn peñol la mayor parte del tajado. Esta es mayor que la otra cercada de tres cercas hecha subida como caracol. Fuerças son que entre indios no se han visto tales. entre la sierra y esta plaça grande esta otra plaça mas pequeña cercada toda de aposentos: en ellos auia muchas mugeres para seruicio de Atabaliba. Antes de entrar en este pueblo ay vna casa cercada de vn corral de tapias: y en el arboleda puesta por mano. Esta casa dizen que es del sol porque en cada pueblo hazen sus mezquitas al sol. Otras muchas mezquitas ay en este pueblo: y en toda esta tierra[1] *las tienen en veneracion. quando entran en ellas se quitan los çapatos a la puerta. La gente de todos estos pueblos despues que se subio a la sierra haze ventaja a toda la otra que queda a tras porque es gente limpia y de mejor razon. y las mugeres muy honestas. Traen sobre la ropa las mugeres vnas reatas muy labradas faxadas por la barriga. sobre esta ropa traen*

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[1] Original: *tierran.*

& vedemmo che sotto la terra circa vna legha era vna casa circundata di arbori, intorno, dellaqual da ogni banda era coperto di alcuni panni bianchi *come tende o padiglioni* piu che mezza legha. quiui era il campo, doue Atabalipa staua à aspettare alla pianura, cosi arriuammo alla terra. *Questa terra Caxamalca è la principale di questo luogho, posta à pie d'una montagna in vna valle circundata da colline, & è di circuito circa quattro*[1] *miglia, passangli appresso duoi bellissimi fiumi, sopra ciascuno de quali è vn ponte, per ilquale si entra nella citta per due porte, ma da vna banda auanti che si entri nella terra, è vn gran palazo circundato da muri a vso di tempio, nella corte delquale ch'è grande: sono piantati varii arbori, liquali fanno ombra, & questo palazzo dicano* 5 r *esser la casa del sole, quale adorono: nellaquale quando entrano si scalzano, & simile a questa sene trouano quasi auanti a ciascuna terra grande. Ma dentro alla terra sono circa .2000. case distinte in strade diritte a filo, la lunghezza dellequali è circa passi*[2] *.200. con muri di pietra forti, & alti passa tre: dentro sono ben partite, con fontane d'acque, molto belle, in mezzo è vna piazza maggior che alcuna d'Hispagna tutta serrata intorno, auanti laquale è vna fortezza di pietra, con vna scala, perlaquale si va di piazza alla detta fortezza. Da vna banda di questa piazza è il palazzo del signore Atabalipa, molto maggiore di tutti li altri, con giardini & loggie grandissime, doue il signore staua tutto il giorno, le habitationi tutte eran dipinte di diuersi colori, & fra glialtri di vno colore rosso che pareua cinabro. in vna delle habitationi ouer loggia erano due grandi*

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[1] Marginal note, 1545: Quatre mil icy se prennent pour une lieu.

[2] Marginal note, 1545: Le pas uault deux piedz & demy.

entro primero el señor Hernando piçarro con alguna gente: y granizaua vn granizo muy grande: en el pueblo auia muy poca gente, que seria quatrocientos o quinientos indios: que guardauan las puertas de las casas del cacique Atabalipa, que estauan llenas de mugeres que hazian chicha para el real de Atabalipa. Luego se aposento el señor gouernador con su gente con harto temor de los muchos indios que estauan el real Cadauno de los christianos dezia que haria mas que Roldan: porque no esperauamos otro socorro, sino el de Dios. El señor Hernando piçarro y el señor Hernando de soto pidieron licencia al señor gouernador: que los dexasse yr con cinco o seys de cauallo y con la lengua a hablar con el cacique Atabalipa: y a ver como tenia assentado su real: El gouernador los dexo yr aunque contra su voluntad. Ellos fueron al real que estaua vna legua de alli. Todo el campo donde el cacique estaua, de vna parte y de otra estaua cercado[1] de esquadrones de gente piqueros y alabarderos y

cubierta vna manta desde la cabeça hasta media pierna que parece mantillo de muger. Los hombres visten camisetas sin mangas y vnas mantas cubiertas. Todas en sus casas texen lana y algodon: y hazen la ropa que es menester y calçado para los hombres de lana y algodon hecho como çapatos.

XEREZ *B8v1:*

La casa de aposento de atabaliba, que en medio de su real tenia es la mejor que entre indios se ha visto, aunque pequeña hecha en quatro quartos: y en medio vn patio y en el vn estanque al qual viene agua por vn caño tan caliente que no se puede sufrir la mano en ella. Esta agua nasce hirviendo en vna sierra que esta cerca de alli. Otra tanta agua fria viene por otro caño: y en el camino se juntan y vienen mezcladas por vn solo caño al estanque. Y quando quieren que venga la vna sola, tienen el caño de la otra. El estanque es grande hecho de piedra. Fuera de la casa a vna parte del corral esta otro estanque no tan bien hecho como este: tiene sus escaleras de piedra por do baxan a lauarse. El aposento donde atabaliba estaua entre dia es vn corredor sobre vn huerto: y junto esta vna camara donde dormia con vna ventana sobre el patio y estanque: : y el corredor assi mesmo sale sobre el patio: las paredes estan enxaluegadas de vn betumen bermejo mejor que almagra que luze mucho: y la madera que cae sobre la cobija de la casa esta teñida de la mesma color. Otro quarto frontero es de quatro bouedas redondas como campanas todas quatro encorporadas en vna. este es encalado blanco como nieue. Los otros dos son casas de seruicio. Por la delantera deste aposento passa vn rio.

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[1] Original: cereado.

fontane ornate di piastre d'oro, in vna dellequali per vno cannone entra acqua calda, talmente che non vi si poteua tener la mano, nell'altra entra acqua freddissima. Escono queste acque della montagna vicina, & entrano nel palazzo, per cannoni, delquale[1] *escono & mescolansi insieme, & si spargono per tutta la terra & seruono alli seruitii necessarii per ciascuno. Gli habitatori sono gente assai netta, & le donne molto honeste, lequali portano sopra lor veste certe cinture lauorate sottilmente, con lequali si fascian quasi tutto il corpo, sopra queste portano a modo d'vn manto, ilquale le cuopre dalla testa infino*[2] *a mezza gamba, gli huomini vestano certe camiciette senza maniche, gli essercitii loro sono, tingere in casa lane & bambagia, per fare quel tanto di tele che gli fa di bisogno, fanno anchora calze di lana & altre in tal modo che gli scusano scarpe.* Et primamente entrò il Signor Hernando Pizarro con alquanta gente, & tempestaua[3] tempesta molto grande. Nella terra era molto poca gente che poteuan esser da quatrocento in cinquecento indiani che guardauan le porte delle case[4] del Cacique Atabalipa, ch' erano piene di donne che faceuano chicha: *cioè vino* per il campo di Atabalipa. subito si alloggio il signor Gouernator con le sue genti, con molto timor della quantita grande de li indiani che erano nella pianura. Ciascuno delli christiani diceuano che fariano piu che Orlando: perche non aspettauano altro soccorso se non quel di Dio. Il signor Hernando Pizarro, & Hernando di Soto domandorono licentia al signor Gouernator che li lasciasse andar con 5 v cinque o sei à cauallo, & con il turcimanno a parlar con il Cacique Atabalipa, & veder come staua alloggiato il suo campo. Il Gouernator li lascio andare (benche contra sua voglia). Et loro andorono al campo, che era vna legha lontano. Tutto il campo doue il Cacique staua: da vna parte & da l'altra era circundato da squadroni di gente, picchieri, alabardieri, & arcieri: & vn'altro squadrone, era

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[1] 1556, 1565: per cannoni, de quali escono. 1606: per cannoni, de'quali escono.

[2] 1556, 1565, 1606: insino.

[3] 1556, 1565, 1606: & faceua tempesta molto grande. 1545: & faisoit alors vng temps moult diuers.

[4] 1545: palais seigneurial.

flecheros: y otro esquadron auia de indios con tiraderas y
hondas: y otros con porras y maças. Los christianos que
yuan passaron por medio dellos: sin que ninguno hiziesse
mudança. y llegaron donde estaua el cacique: y hallaron
lo que estaua assentado a la puerta de su casa: con muchas
mugeres al derredor del: que ningun indio osaua estar cerca
3 v del. Y llego hernando de soto con el cauallo sobre el: y el se
estuuo quedo sin hazer mudança: y llego tan cerca que vna
borla que el cacique tenia tocada puesta en la frente le auentaua
el cauallo con las narizes: y el cacique nunca se mudo.
El capitan Hernando de soto saco vn anillo del dedo, y se lo
dio en señal de paz y amor de parte de los chrstianos. El
lo tomo con muy poca estima: luego vino Hernando piçarro
que se auia quedado algo a tras a poner tres o quatro de
cauallo en vn puerto donde auia mal passo: y traya a las
ancas del cauallo vn indio que era la lengua: y allego se al
cacique con muy poco temor del y de toda su gente: y dixo
le que alçasse la cabeça, que la tenia muy baxa, y que le
hablasse, pues el era su amigo, y le venia a ver: y rogo le
que por la mañana fuesse a ver al gouernador, que le desseaua
mucho ver. El cacique le dixo con la cabeça baxa,
que el yria por la mañana a ver le. Dixo el capitan que

XEREZ *B8r2/v1:*

Las armas que se hallaron con que hazen la guerra y su manera de pelear es la siguiente. En la delantera vienen honderos que tiran con hondas piedras guigeñas lisas y hechas a mano de hechura de hueuos. los honderos traen rodelas que ellos mesmos hazen de tablilllas angostas y muy fuertes. assi mesmo traen jubones colchados de algodon. Tras de estos vienen otros con porras y hachas de armas las porras son de braça y media de largo, y tan gruessas como vna lança gineta: la porra que esta al cabo engastonada es de metal tan grande como el puño con cinco o seys puntas agudas tan gruessa cada punta como el dedo pulgar. juegan con ellas a dos manos. las hachas son del mesmo tamaño y mayores: la cuchilla de metal de anchor de vn palmo como alabarda. Algunas hachas y porras ay de oro y plata que traen los principales tras estos vienen otros con lanças pequeñas arrojadizas como dardos. en la retaguarda vienen piqueros con lanças largas de treynta palmos: en el braço yzquierdo traen vna manga con mucho algodon sobre que juegan con la porra. todos vienen repartidos en sus esquadras con sus vanderas y capitanes que los mandan, con tanto concierto como turcos. Algunos dellos traen capacetes grandes que les cubren hasta los ojos hechos de madera, y en ellos mucho algodon que de hierro no pueden ser mas fuertes.

di Indiani, con frombe, & alcuni con certe mazze *di lunghezza d'vn braccio & mezzo, & grosse come vna hasta di giannetta, con vna palla tonda in cima grossa vn pugno, nella quale sono fitte cinque o sei punte di pietra dura grosse vn dito, & queste adoperano a due mani. Li principali portano le mazze, & alcuni accette d'oro & d'argento, altri portano lancette per tirare a modo di partigianette, quelli della retroguardia portano lancie lunghe circa palmi*[1] *trenta, & in vn delli bracci portano vna manicha ripiena di bambagia, & alcuni hanno in testa celate che gli cuoprono infino sopra gli occhi, fatte di canne tessute con molta bambagia, tal che di ferro non sarebber tanto forti.* Li christiani che andauano passorono per mezzo di loro, senza che alchuno facesse mouimento, & arriuorno doue staua il Cacique. & trouoronlo che sedeua alla porta del suo alloggiamento, con molte donne dietro,[2] & nissuno indiano ardiua stargli a torno, & arriuo Hernando di Soto con il cauallo sopra di lui, & lui stette quieto senza far mouimento alcuno. & gli arriuo tanto appresso che il cauallo con le nari gli suentolaua vn fiocco che lui teneua legato in su la fronte, *di lana tanto fino che pareua di seta chermisi,* & mai si mosse. Il capitan Hernando di Soto si cauo vno anello di dito, & glielo dette in segno di pace & amor, da parte delli christiani: & lui lo prese con poca estimatione,[3] & subito venne Hernando pizarro che era rimasto alquanto a dietro, per metter tre ouer quattro caualli in vn luogho doue era vn mal passo: & portaua in groppa del cauallo vn indiano, che era il turcimanno, & arriuo al Cacique, con poca paura di lui & delle sue genti. & gli disse ch'alzasse il capo, qual teneua molto basso, & gli parlasse, poi che era suo amico, & lo veniua a vedere, & pregollo che la mattina poi fusse a veder il Gouernator che desideraua molto di vederlo. il Cacique li disse con la testa bassa, che andarebbe la mattina a vedergli.[4] Disse il capitano

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[1] Marginal note, 1545: La paulme contient quatre doigtz.

[2] 1545: & derriere luy vne grande compagnie de dames.

[3] 1545: lequel il receut bien que d'un assez maigre visage comme faisant bien peu de cas tant du don que du donneur.

[4] 1556, 1565, 1606: vederlo.

venian cansados del camino, que les mandasse dar a beuer. El cacique embio dos indias, y truxeron dos copones grandes de oro para beuer: y ellos por contenter le hizieron que beuian: pero no beuieron: y despidieron se del. Hernando de soto arremetio el cauallo muchas vezes por junto a vn esquadron de piqueros: y ellos se retruxeron vn passo a tras. Despues de ydos los christianos de alli, ellos pagaron bien lo que se retruxeron: que a ellos y a sus mugeres e hijos mando el cacique cortar las cabeças, diziendo que adelante auian ellos de yr, que no boluer a tras: y[1] que a todos los que boluiessen a tras auia de mandar hazar otro tanto. Los capitanes boluieron al señor gouernador: y le dixeron todo lo que auian passado con el cacique: y que les parecia que la gente que tenia serian quarenta mil hombres de pelea: y esto dixeronlo por esforçar a la gente, que mas auia de ochenta mil. y dixeron lo que el cacique les auia dicho. Aposentada aquella noche la gente, no quedo chico ni grande a pie ni a caullo, que todos anduuieron con sus armas rondando se aquella noche: y assi mesmo el buen viejo del gouernador, que andaua esforçando la gente. Aquel dia todos eran señores. Otro dia por la mañana no hazian sino yr y venir mensageros al real de Atabalipa: y vna vez dezia que auia de venir con sus armas: otra vez dezia que auia de venir sin ellas. El gouernador le embio a dezir que viniesse como quisiesse, que los hombres bien parecian con sus armas. A hora de medio dia començo Atabalipa a partir de su real con tanta gente que todos los campos[2] venian llenos. y todos estos indios trayan vnas patenas grandes de oro y plata como coronas en las cabeças: parecia que venian todos con sus arneses vestidos. A hora de bisperas començaron a entrar por el pueblo: y alli estuuo el cacique esperando vn poco a su gente porque viniessen todos juntos. Quando todos fueron llegados, hecha su ordenança mouio para entrar

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[1] Original: a trasr y.

[2] Original: cnmpos.

che[1] veniuan stracchi del camino, ch'el comandasse che li fusse dato da bere. Il Cacique chiamo due indiane, qual portorono due gran 6 r coppe d'oro per darli da bere: & quelli per contentarlo finseno di bere, ma non beuerono, & si espedirono da lui. Hernando di Soto rimesse il cauallo molte fiate alla volta di vno squadrone de picchieri, & loro si ritirorno vn passo indietro. Dapoi partiti li christiani loro pagorono bene quelli che s'erano tirati in dietro, che ad essi & a sue mogliere, & figliuoli comando il Cacique che fusse tagliata la testa, dicendoli che doueuano andar auanti & non tornar indietro, & che a tutti quelli che ritornasseno in dietro: comanderia fusse fatto il medesimo. Li capitani ritornorno al signor Gouernator, & li disseno quel che era seguito del Cacique, & che li pareua che la gente ch'egli haueua potriano esser da .40. milia huomini da guerra. Et questo disseno per dar animo alla gente, perche erano piu di 80. milia. & disseno *anchora* quello che li haueua detto il Cacique. Alloggiata quella notte la gente, non fu piccol ne grande, a pie, ne a cauallo, che tutta quella notte non andasseno con le sue arme, facendo le guardie. Et similmente il buon vecchio del Gouernatore, qual andaua facendo animo alla gente, che in quel giorno tutti fussero valenti.[2] L'altro giorno da mattina non faceua altro che andar & venir nuntii[3] al campo di Atabalipa, qual vna volta diceua di voler venire con le armi, altra volta di venir senza quelle. Il Gouernatore li mando à dir che venisse come volesse che li huomini pareuano buon con le sue armi. A l'hora di mezzo giorno si comincio a partir con il suo campo con tanta gente, che tutti campi erano pieni, & tutti questi indiani portauano vna diadema grande di oro & di argento, come vna corona in testa, & veniuan tutti vestiti con li suoi vestimenti.[4] A hora di vespro eran arriuati tutti alla citta, alla porta della quale era fermo il Cacique, & iui stette aspettando le sue genti, accioche tutti intrassero vniti. ilquale quando tutti furono arriuati, fatta la sua ordinanza, mosse *con tutta la*

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[1] 1556, 1565, 1606: perche.

[2] 1545: aduertissant vn chacun de son deuoir, & par vertueuses exhortations accroissant le cueur aux plus lasches.

[3] 1556, 1565, 1606: messi.

[4] 1545: vestuz de tous leurs accoustremens.

adelante: y llego con sus andas en medio dela plaça: aunque lleuaua algun recelo. El gouernador le embio luego vn hombre embiandole a rogar que viniesse donde el estaua: assegurando le que no recibiria ningun daño: ni enojo: por tanto que bien podia venir sin temor: aunque el cacique no mostraua tener ninguno. El cacique traya delante de si vestidos de vna librea quatrocientos indios: los quales venian quitando delante del todas las piedras y pajas que hallauan por el camino por donde lleuauan al cacique en las andas. y aquellos quatrocientos hombres trayan debaxo de aquellas libreas vnas porras de armas secretamente: y assi meesmo jubones de armas fuertes: y vnas hondas con sus piedras hechizas para ellas. El gouernador tenia su gente puesta en tres casas muy grandes que tenia cadauna mas de dozientos passos y veynte puertas. En vna destas casas estaua el señor capitan hernando piçarro con catorze o quinze de cauallo: en la otra estaua el señor capitan Hernando de soto con otros quinze o diez y seys de cauallo assi mesmo estaua en la otra casa Benalcaçar con otros tantos, pocos mas o 4 r menos. En otra estaua el señor governador con dos o tres de cauallo y con veynte o veynte y cinco hombres de pie: y toda la otra gente estauan guardando las puertas porque ninguno entrasse dentro de vna fortaleza muy fuerte que estaua en medio de la plaça: en la qual estaua Pedro de candia capitan por su magestad con ocho o nueue escopereros y quatro tiros de artilleria, breços pequeños: que guardaua aquella

Xerez *B7r1:*

Luego la delantera de la gente comenco a entrar en la plaça. venia delante vn esquadron de indios vestidos de vna librea de colores a manera de escaques: estos venian quitando las pajas del suelo y barriendo el camino. Tras estos venian otras tres esquadras vestidos de otra manera todos cantando y baylando. Luego venia mucha gente con armaduras, patenas, y coronas de oro y plata: Entre estos venia atabaliba en vna litera aforrada de pluma de papagayos de muchas colores guarnecida de chapas de oro y plata. Traian le muchos indios sobre los hombros en alto tras desta venian otras dos literas y dos hamacas en que venian otras personas principales. luego venia mucha gente en esquadras con coronas de oro y plata

sua gente per andar auanti *in questo modo.* Auanti andauano quattrocento indiani vestiti tutti à vna liurea, *liquali niente altro faceuano che nettare la strada* leuando via tutte le pietre, o paglia che trouauan per il camino, donde doueua passar il signor portato in lettica.[1] & sotto quelle veste à liurea portauan certe mazochie secretamente, con giubboni forti, con frombe & pietre fatte a posta per quelle. *dopo questi veniuan tre squadre vestiti a vn'altra liurea, liquali andauan cantando & ballando. questi seguitaua altra gente armata, & con diademe d'oro & d'argento in testa: fra questi era il gran Cacique Atabalipa,* 6 v *vestito d'vna veste di lana finissima che pareua di chermisi, con oro tirato ouer battuto benissimo tessuto. La lettica sopra la quale era portato, era molto alta & marauigliosa, perche era foderata di penne di pappagalli di diuersi colori, & ornata di pietre preciose tutte legate in oro & argento, portata da indiani vestiti di penne di pappagallo di diuersi colori, dietro alla quale veniuon due altre ricchissime, nellequali erano altri personaggi principali appresso al signore,* benche hauesse qualche sospetto *lui & tutta la sua gente.* Il *signor* Gouernator li mando subito vn huomo pregandolo che venisse doue lui staua, dandoli sicurta che non riceuerebbe alcun danno ne dispiacere, per tanto che ben poteua venir senza paura, anchor ch'el Cacique non mostrasse hauerne. Il Gouernator hauea alloggiate le sue genti in case molto grandi, che era lunga ciascuna di quelle piu di dugiento passi, & vniti.[2] in vna di queste case staua il signor Hernando Pizarro con quattordici o quindici a cauallo. nell'altra staua il Signor Hernando di Soto con altri quindici o sedici[3] a cauallo, similmente staua Belchazar con altretanti, poco piu o manco: nell'altra staua il signor Gouernator con duoi o tre a cauallo, & con venti o venticinque huomini a piedi: & tutta l'altra gente staua alla guardia delle porte d'vna fortezza molto forte, che alchun non intrasse dentro. laqual era in mezzo la piazza. & in quella Pietro di Candia, Capitano per sua Maesta con otto, o noue schioppetti, & quattro pezzi piccoli d'arti-

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[1] 1556: letiga. 1565, 1606: lettica.

[2] 1556, 1565: & vniti, in vna di queste case. 1606: & vniti in vna di queste case. 1545: en plusieurs maisons dont la moindre auoit plus de deux cens pas de longueur en l'une desquelles fut logé le seigneur Hernand Pizzarre auec quatorze ou quinze cheuaux.

[3] 1545: auec autres seize cheuaux.

fortaleza que tenia por mandado del governador: el gouernador le tenia mandado que si hasta diez indios subiessen en ella que los dexasse sobir, y mas no. Quando el cacique llego en aquella plaça, dixo donde estan estos christianos? ya estan todos escondidos, que no parece ninguno? En esto se subieron siete o ocho indios en aquella fortaleza. Y vn capitan con vna pica muy alta con vna vandera hizo vna seña que viniessen las armas porque el piquero que venia a tras traya las picas de los que venian adelante: desta manera parecian sin armas, y venian con ellas Y vn frayle de la orden de santo Domingo con vna cruz ✠ en la mano queriendo le dezir las cosas de Dios, le fue a hablar: y le dixo, que los christianos eran sus amigos: y que el señor gouernador le queria mucho y que entrasse en su posada a ver le. El cacique respondio que el no passaria mas adelante hasta que le boluiessen los christianos todo lo que le hauian tomado en toda la tierra y que despues el haria todo lo que le viniesse en voluntad. Dexando el frayle aquellas platicas, con vn libro que traya en las manos le empeço a dezir las cosas de Dios que le conuenian: pero el no las quiso tomar: y pidiendo el libro, el padre se lo dio, pensando que lo queria besar: y el lo tomo, y lo echo encima de su gente. y el mochacho que era la lengua, que alli estaua diziendole aquellas cosas, fue corriendo luego: y tomo el libro, y diolo al padre: y el padre se boluio luego dando bozes, diziendo, salid salid christianos, y venid a estos enemigos perros, que no quieren las cosas de Dios: que me ha echado aquel cacique en el suelo el libro de nuestra santa ley. Y en esto hizieron señas al artillero que soltasse los tiros por medio dellos. y assi solto los dos dellos, que no pudo soltar mas. y los indios que auian subido a la fortaleza no descendieron por

XEREZ *B7r2/v1:*

Luego soltaron los tiros y tocaron las trompetas: y salio la gente de pie y de cauallo. Como los indios vieron el tropel de los cauallos, huyeron muchos de aquellos que en la plaça estauan. Y fue tanta la furia con que huyeron que rompieron vn lienço de la cerca de la plaça: y muchos cayeron vnos sobre otros . . . En todo esto no alço indio armas contra español: porque fue tanto el espanto que tuuieron de ver entrar al gouernador entre ellos: y soltar de improuiso el artilleria y entrar los cauallos de tropel: como era cosa que nunca auian visto:

glieria che guardauan quella fortezza, qual teneuan per comandamento del Gouernatore. Ilquale hauea loro comandato che se fino a dieci indiani intrassero in quella, che gli lasciasse intrar, ma piu no. Quando il Cacique arriuo in su la piazza disse. Doue sono questi christiani? mi par che siano tutti ascosi che non ne appar alcuno. In questo mezzo introrno[1] sette, o otto indiani in quella fortezza, & vno Capitano con vna piccha molto lungha, con vna bandiera, fece vn segnal che venissero con le armi. per cio che li picchieri che veniuano adietro portauano le picche di quelli che andauano auanti, & cosi pareuano senza armi, & pur veniuano con quelle. Allhora vn frate de l'ordine di san Domenico, con vna croce in mano, volendoli dire alcuna cosa di Dio, li ando a parlare, & li disse che li christiani erano suoi amici, & ch'el signor Gouernator desideraua che lui venisse nel suo alloggiamento a vederlo. Il Cacique li rispose ch'el non passaria 7 r piu auanti, fin tanto che li christiani non li rendessero tutto quello che li haueuan tolto in tutta la terra, & che poi faria tanto quanto li venisse in volonta. lasciando il frate tal pratiche con vn libro qual portaua in mano li comincio a dir le cose di Dio che li pareuano a proposito, ma lui non le volse accettare, & domandando il libro, il padre glie lo dette: pensando che lo volesse baciare, & lui presolo lo butto addosso[2] le sue genti. Lo indiano che era turcimano sendo presente quando li diceua quelle cose, subito corse & prese il libro: & dettelo al padre, ilquale si ritorno subito indietro gridando: saltate fuora, saltate fuora christiani, & venite a questi inimici cani, che non vogliono accettar le cose di Dio, che mi ha buttado[3] il Cacique in terra il libro della nostra santa legge. In questo *il Gouernatore fece sonar le trombe, &* dette segno al bombardiere che scaricasse l'artiglieria, ilche fu fatto, *& gli spagnuoli a piedi & a cauallo vsciron con tanta furia addosso a gli indiani, che quegli vdito lo spauenteuol strepito della artiglieria, & veduto l'impeto delli caualli: si missono in fuga.* & quelli che erano montati in su la fortezza non discesero donde

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[1] 1556: intrornoò sette, otto. 1565, 1606: introrono sette, ò otto.

[2] 1545: il le feit voller par dessus les testes de ses gens.

[3] 1556, 1565, 1606: gettato.

donde auian subido, antes los hizieron saltar de la fortaleza abaxo. Viendo esto la gente de cauallo que en las tres casas estaua, salio toda como tenian concertado: y assi mesmo salio el governador con la gente de pie que consigo tenia: y fue derecho a las andas donde estaua aquel señor. Y muchos de los de pie que lleuaua se apartaron algo del, viendo que eran muchos los indios contrarios. y por vengarse mas dellos, con la poca gente que le quedo, el governador llego a sus andas, aunque no le dexauan llegar: que muchos indios tenian cortadas las manos, y con los hombros tenian las andas de su señor: aunque no les aprouecho su esfuerço: porque todos fueron muertos y su señor preso por el governador. Con aquellos pocos de pie que lleuaua: y con la gente de cauallo salio al campo: y muchos dellos cayeron sobre los indios que yuan huyendo, que eran tantos, que por huyr derribaron vna pared de seys pies en ancho: y mas de quinze de largo y de altura de vn hombre: en esta cayeron muchos de cauallo. y en espacio de dos horas (que no serian mas de dia) toda aquella gente fue desbaratada. Y en verdad no fue por nuestras fuerças, que eramos pocos: sino por la gracia de Dios que es mucha Quedaron aquel dia muertos en el campo seys, o siete mil indios, sin otros muchos que lleuauan los braços cortados y otras heridas. y aquella noche anduuo la gente de cauallo y la de pie por el pueblo: porque vimos cinco o seys mil indios en vna sierra que esta encima del pueblo: y andouimos guardando nos dellos. Porque los christianos se recogessen al real, mando el gouernador soltar vn tiro de artilleria: y luego se recogeron los de cauallo que andauan en el campo pensando que indios dauan en el real, y assi mesmo los de pie, siendo passados quatro o cinco horas de la noche. El governador estaua muy alegre con la victoria que Dios nuestro señor nos hauia dado: y dixo al cacique,

con gran turbacion procurauan mas huyr por saluar las vidas que de hazer guerra. Todos los que traian las andas de Atabaliba parecio ser hombres principales los quales todos murieron, y tambien los que venian en las literas y hamacas. El de la vna litera era su page y gran señor a quien el mucho estimaua: y los otros eran señores de mucha gente y consegeros suyos. murio tambien el cacique señor de Caxamalca.

eran montati, ma ne furon buttati a terra. & similmente vsci il Gouernatore con quella gente a pie che hauea seco, & ando à dirittura alla lettica, nellaquale era il signor *Atabalipa:* & molti di quelli a pie che andauano auanti, si ritirorono alquanto da lui: vedendo che *con il signor Gouernatore* erano molti indiani suoi inimici:[1] *per il che* il *signor* Gouernatore si approssimo con le sue genti alla lettica anchor che non lo lasciassero arriuare. perche molti indiani alliquali eran state tagliate le mani, con le spalle teneuano la lettica del signore. ma poco giouò il loro sforzo, perche tutti furono morti *insieme con altri signori, liquali eran portati in lettica.* & il signor fu preso per il Gouernator, *ilquale, fatto cuore* con quelli pochi pedoni che haueua, & con la gente à cauallo vsci alla campagna: & molti di loro si missero à seguitare li indiani che andauano fuggendo: liquali eran tanti che per fuggir detteno in vn muro di sei pie di grossezza, & piu di quindici di lunghezza, & altezza di vn huomo, & quello rouinorono. sopra lequali ruine caddero molti da cauallo. & in spatio di due hore che non era piu giorno tutta quella gente fu posta in rotta. & veramente non fu per le nostre forze che erauamo pochi, ma solo per la gratia di Dio. Rimasero in quel giorno morti da sei ouer sette milia indiani, oltra molti che haueano tagliate le braccia, & *molte* altre 7 v ferite. & in quella notte andò circuendo la gente à cauallo & à pie, la terra: perche si vedeuan cinque, ouero sei milia indiani in vna montagna che soprastaua alla terra, delli quali haueuamo qualche sospetto. & accioche li christiani si tornassero in campo, comando il Gouernatore che si tirasse vn colpo di artiglieria, *ilqual tratto* subito ritornorno quelli che erano sparsi per il campo: dubitando che li indiani non li assaltassero, & similmente li huomini da pie. Essendo passate quattro, o cinque hore de la notte, il Gouernatore staua molto allegro per la vittoria che Dio gli haueua dato: & *al contrario*[2]

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[1] 1545: Alors sortit le gouuerneur de son logis auec ce peu de gens qu'il auoit, court droict à la lictiere royalle, laquelle les premiers des siens vouloient desia assaillir quand ilz furent contrainctz de tourner bride pour donner secours à leur seigneur qu'ilz apparceurent enuahy de ses ennemys.

[2] 1545: le gouuerneur feit tyrer vn coup de canon, pour le son de la retraicte. Or si le visage, & maintien du gouuerneur, & du Cacique estoyent bien lors differendz, il ne le conuient demander: car par raison autant sentoit l'un d'ayse, & de contentement que l'autre de tourment, & naturel creuecueur. Mais sur les quatre heures de la nuyt le bon gouuerneur se meit en propos auec Atabalipa pour le reconforter.

que porque estaua tan triste: que no deuia tener pensar:[1]
4 v que nosotros los christianos no hauiamos nascido en su tierra sino muy lexos della: y que por todas las tierras por donde auiamos venido auia muy grandes señores: a todos los quales auiamos hecho amigos y vasallos del emperador por paz o por guerra: y que no se espantasse por auer sido preso de nosotros. El respondio medio riendo, que no estaua pensatiuo por aquello, sino porque el tuuo pensamiento de prender al gouernador: y que le hauia salido al contrario: que a esta causa estaua tan pensatiuo. Mas que pedia por merced al señor gouernador, que si por alli estaua algun indio de los suyos que lo mandasse venir porque queria hablar con el. Luego se mando el señor gouernador traer dos indios principales de los que hauian tomado en la batalla. El cacique les pregunto si hauia mucha gente muerta: ellos le dixeron que todos los campos estauan llenos. Luego embio a dezir a la gente que quedaua que no huyessen: sino que lo viniessen a seruir, pues que el no era muerto: mas estaua en poder de los christianos: y que a el le parecia que los christianos eran buena gente: por tanto les mandaua que los viniessen a seruir. El gouernador pregunto a la lengua que era lo que auia dicho: la lengua se lo declaro todo El gouernador dixo que mas auia que les dezir: y haziendo vna cruz ✠ diola al cacique diziendo le que toda su gente assi junta como apartados vnos de otros tuuiesse cadauno en la mano vna ✠ como aquella. y que los christianos de cauallo y de pie saldrian por la mañana al campo, y matarian a los que hallassen sin aquella señal de la cruz ✠

XEREZ *B8r1:*

assi se fueron a cenar: y el gouernador hizo sentar a su mesa a Atabaliba haziendo le buen tratamiento: y siruieron le como a su mesma persona: y luego le mando dar de sus mugeres que fueron presas las que el quiso para su seruicio: y mando le hazer vna buena cama en la camara que el mesmo gouernador dormia: teniendo lo suelto sin prision, sino las guardas que velauan.

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[1] Original: pesar.

il Cacique staua molto maninconoso, alqual domandando il Gouernator la causa & dicendogli che non douea hauer affanno di noi altri christiani: che noi non erauamo nati nelle sue terre, ma molto lontani da quelle, & che per tutte le terre donde eramo venuti, erano molto gran signori, liquali tutti ci haueuamo fatti amici & vassalli del Imperatore, per pace, o per guerra. & che lui non hauesse paura per essere stato preso da noi. *Il Cacique* rispose mezzo ridendo, che non staua pensoso per quello: ma perche hebbe pensier di prender il Gouernator, laqual cosa gli era riuscita al contrario: & per tal causa staua con tanto dolore. ma che di gratia domandaua al signor Gouernatore che se iui era alcun indiano de suoi, che lo facesse venire, perche voleua parlar con lui. subito comando il signor Gouernatore che fussero menati duoi indiani principali di quelli che haueua presi nella battaglia. a quali il Cacique li domandò che quantita di gente era morta della sua: loro risposeno che tutti li campi erano pieni di morti. Allhora quello subito mandò a dire a *tutta* la gente che era rimasta che non fuggissero: anzi che lo venissero a trouare, poi che non era morto, & che era in mano delli christiani, liquali gli pareua fussero buona gente: per tanto comandaua loro che lo venissero a seruire. Il Gouernatore dimandò al turcimanno quello che hauea detto *il Cacique*, quale gli dechiaro il tutto. Il Gouernatore allhora fatta vna croce la dette al Cacique, dicendogli *che ordinasse* che tutta la sua gente, cosi vnita come separata l'un da l'altro, ne portasse vna in mano simile à quella: perche li christiani a cauallo & a pie vsciriano la mattina sequente al campo, & amazzariano tutti quelli che trouassero senza quel segnale. *Quella sera il signor Gouernatore fece sedere alla sua tauola questo gran Cacique Atabalipa con gran carezze, & volse che fusse seruito dalle sue donne che erano state prese, & comando* 8 r
che gli fusse parato vn ricco letto, in quella camera doue dormiua lui, lasciandolo dislegato ma con guardie. Era questo signore di anni

y el otro dia por la mañana salieron todos al campo con mucho concierto. y hallaron muchos esquadrones de los indios. el delantero de todos lleuaua en las manos vna cruz con el grande temor que tenian. Recogiosse mucho oro que auia en algunos toldos, y derramado por los campos: assi mesmo muchas ropas. Todo esto recogeron los negros y los indios de seruicio: que los otros estauan en orden guardando sus personas. recogeronse cincuenta mil pesos de oro. En aquella noche y dia, ya que el cacique mostraua estar contento, dixo al gouernador que bien sabia lo que ellos buscauan. El gouernador le dixo que la gente de guerra no buscaua otra cosa sino oro para ellos y para su señor el emperador. el cacique dixo que el les daria tanto oro como cabria en vn apartado que alli estaua hasta vna raya blanca que alli estaua, que vn hombre alto no allegaua a ella con

Xerez *C1r2/v1:*

¶ Atabaliba era hombre de treynta años, bien apersonado y dispuesto, algo gruesso, el rostro grande hermoso, y feroz, los ojos encarniçados en sangre: hablaua con mucha grauedad como gran señor. hazia muy biuos razonamientos: que entendidos por los españoles, conoscian ser hombre sabio era hombre alegre aunque crudo. Hablando con los suyos era muy robusto: y no mostraua alegria.

Xerez *B8v1/2:*

Su padre deste Atabaliba se llamo Cuzco que señoreo toda aquella tierra: de mas de trezientas leguas le obedecian y dauan tributo. Fue natural de vna prouincia mas a tras de Guito: y como hallasse aquella tierra donde estaua aplazible y abundosa y rica, assento en ella: y puso nombre a vna gran ciudad donde el estaua la ciudad del Cuzco. Era tan temido y obedescido que lo tuuieron quasi por su dios: y en muchos pueblos le tenian hecho de bulto. Tuuo cien hijos e hijas, y los mas son biuos. ocho años ha que murio y dexo por su heredero a vn hijo suyo llamado assi como el. Este era hijo de su muger ligitima. Llaman muger ligitima ala mas principal a quien mas quiere el marido. este era mayor que atabaliba.

Xerez *B8r1:*

El capitan con los de cauallo recogio todo lo que auia en el campo y tiendas de atabaliba: y entro antes de medio dia en el real con vna caualgada de hombres y mugeres y ouejas y oro y plata y ropa. en esta caualgada huuo ochenta mil pesos y siete mil marcos de plata y catorze esmeraldas. el oro y plata en pieças monstruosas y platos grandes y pequeños y cantaros y ollas y braseros y copones grandes y otras pieças diuersas. Atabaliba dixo que todo esto era baxilla de su seruicio: y que sus indios que auian huydo auian lleuado otra mucha quantidad.

trenta in circa, ben disposto della persona, vn poco grasso, con labra grosse, & con occhi incarnati come di sangue. & parlaua con molta grauita. Il padre fu chiamato Cusco signor di quel paese, ilquale era di circuito di circa trecento leghe. delquale cauaua gran tributo. la patria & signoria sua non era questa prouincia, ma vna altra lontana molto di qui, chiamata Guito, della qual partendosi & arriuando in questo paese ci si volse fermare, per hauerlo trouato bello, abondante, & ricco, & pose nome à vna delle citta principali Cusco, dalla quale fu poi cosi chiamata tutta la prouincia. fu temuto & vbidito, & dopo la morte fu tenuto per Iddio, & in molte terre gli furon fatte statue. hebbe cento figliuoli fra maschi & femine: fra quali fu Atabalipa, & vnaltro[1] *chiamato parimente Cusco, lasciato dal padre*[2] *herede della signoria: con ilquale in questo tempo Atabalipa faceua guerra, & haueuagli tolto tutto lo stato.* L'altro giorno da mattina vscirono tutti li christiani al campo con molto ordine, & trouorono molti squadroni di indiani: Il primo di tutti portaua in mano vna croce per gran paura che haueano. & si raguno assai oro che era in alcuni padiglioni & sparso per li campi, & similmente molti panni. questo medesimo ragunorno li negri & indiani da seruitio, che[3] li altri stauano in ordinanza guardando le sue persone. Et accumulò cinquanta milia pesi d'oro *che val ciascun peso vn ducato largo &*[4] *duoi carlini,*[5] *& sette milia marche d'argento, & molti smeraldi.* dil che il Cacique mostraua esser contento: & disse al gouernator *che questi ori erano de la sua credenziera per la sua tauola:* che ben sapeua quel che andauano cercando. Il gouernator rispose che da la gente di guerra non si cercaua altro che oro, per se, & per il suo signor Imperadore. Il Cacique disse che lui gli daria tanto oro quanto staria in vna stanza *da parte,* che iui era fino vn segno bianco, che vi era tanto alto, che vn huomo ben grande non vi arriuaua a vn palmo

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[1] 1556, 1565, 1606: vn'altro.

[2] Original: padte.

[3] 1556, 1565, 1606: perche.

[4] 1545: le pesant valloit vn double ducat, deux carlins.

[5] Marginal note, 1545: Carlin est une piece de deux solz.

vn palmo: y seria de veynte cinco pies en largo y quinze en ancho. Preguntole el gouernador que quanta plata le daria? el cacique dixo: que trayria diez mil indios: y que harian vn cercado en medio de la plaça: y que lo henchiria todo de vasos de plata. Que todo esto le daria porque lo pusiesse en su libertad como antes estaua. El gouernador se lo prometio, con tanto que no hiziesse traycīon: y pregunto le que en quantos dias traeria aquel oro que dezia?: el respondio que en los quarenta dias siguientes lo traeria: y que porque la quantidad era mucha: que el yria a vna prouincia llamada Chincha: y de alli traeria la plata que auia mandado. En esto se passaron obra de veynte dias que no vino oro: a cabo de los quales truxeron ocho cantaros de oro con otros muchos vasos, y otras pieças. Alli supimos como este cacique auia prendido a otro señor que se dezia el Cuzco que era mayor señor que el: este era su hermano de padre y no de madre. y el mesmo Cuzco que venia preso supo como los christianos hauian prendido a su hermano:[1] y dixo si yo viesse a los christianos, yo seria señor porque tengo gran desseo de ver los: y yo se que vienen en busca mia: y que Atabalipa les prometio vn bohio de oro que yo tenia para darles: mas yo les daria quatro bohios y ellos no me matarian, como este pienso que me ha de matar: Luego que Atabalipa supo lo que su hermano el Cuzco auia dicho tuuo gran temor que sabiendo esto los christianos luego lo matarian y alçarian 5 r por señor al Cuzco su hermano: y mando que lo matassen prestamente: y assi lo mataron, que no aprouecho el mucho temor que el gouernador puso al Atabalipa quando supo que vn capitan suyo lo tenia, dixole que no lo mandasse matar: sino que lo hiziesse traer alli a donde estauan. El mesmo Atabalipa pensaua ser señor porque hauia conquistado la tierra: pocos dias antes en vna prouincia que se dize Gomachuco auia muerto mucha gente: y hauia prendido a vn hermano suyo, el qual hauia jurado de beuer con la cabeça del mesmo Atabalipa: y el Atabalipa beuia con la suya: porque yo lo vi, y todas los que se hallaron con el señor

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[1] Original: end of line 42, "her"; beginning of line 43, "hermano:".

appresso, & era di .25. pie di lunghezza, & quindici di larghezza. *Allhora* gli dimandò il Gouernatore quanto argento li daria. Il Cacique rispose che condurria dieci milia indiani, che fariano vn serraglio in mezzo della piazza, & che lo impiria tutto de vasi[1] d'argento, *cioè olle, pignatte, secchi, & altri vasi,* & questo li daria accioche lo rimettesse in sua liberta. Il Gouernator gli promesse: ma con questo che non facesse alcun tradimento *a christiani,* & li dimandò in quanti giorni faria portar quel oro che diceua. Alquale 8 v rispose, che in quaranta di seguenti si portaria: & perche la quantita era molta, che mandaria ad vna prouincia chiamata Chincha, & da quella faria portar l'argento che haueua comandato. In questo passò vn spacio di venti giorni che non venne oro. In capo delli quali portorono otto cantari fatti d'oro, *che sono come pignatte grandi* con molti altri vasi & altre piastre. Allhora intendemmo come questo Cacique haueua preso Cusco suo fratello, di padre ma non di madre: qual era maggior signor di lui. Et il medesimo Cusco venendo condotto preso, seppe come li christiani hauean preso suo fratello *Atabalipa:* & disse *a quelli che lo menauano.* Se io vedessi li christiani io saria signore, per questo ho gran desiderio di vedergli: & io so che mi vengono a cercare, & che Atabalipa ha lor promesso gran quantita d'oro, che io haueuo per dar loro: ma io gli daria quattro volte tanto, & loro non mi amazzariano, come penso che costui fara. Subito che Atabalipa intese quel che suo fratello Cusco haueua detto: hebbe gran paura, che sapendo questo li christiani, non lo facessino subito morire, & facessin signor suo fratello. Per questo comandò che subitamente fusse morto, & cosi fu fatto. che non li giouò il molto timor messo ad Atabalipa dal Gouernatore: quando seppe che vn suo capitano lo teneua prigione, con dirgli che non lo lasciasse amazzar, ma che lo facesse venir al loro alloggiamento. Atabalipa si pensaua esser signore, perche haueua conquistato quel paese, & pochi giorni auanti in vna prouincia che si chiama Gomachuco haueua fatto morir assai gente, & hauea preso vn' *altro* suo fratello, qual haueua giurato di beuer con la testa del detto Atabalipa: ma *per il contrario,* Atabalipa beuea[2] con la sua. Ilche io vidi & tutti quelli che si trouorno

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[1] 1545: vaisselle d'argent: comme de potz de cuysine, quartes, sceaux, & telles autres vtensilles, qui seroit le pris de sa rançon.

[2] Original: beeua.

Hernando piçarro: y el vio la cabeça con su cuero, y las carnes secas y sus cabellos: y tiene los dientes cerrados: y alli tiene vn cañuto de plata: y en cima de la cabeça tiene vn copon de oro pegado, por donde beuia atabalipa quando se le acordaua de las guerras que su hermano le auia hecho: y echauan la chicha en aquel copon y saliale por la boca y por el cañuto por donde beuia. ¶ En estos dias trayan algun oro. y el señor gouernador supo que auia vna mezquita muy rica en aquella tierra: y que en esta mezquita auia tanto oro, y aun mas de aquello que el cacique hauia prometido: porque todos los caciques de aquella tierra adorauan en ella: y assi mesmo el Cuzco: que alli venian a tomar sus consejos sobre lo que auian de hazer: y muchos dias del año venian a vn cimin que tenian hecho de oro: y le dauan a beuer vnas esmeraldas molidas. Sabiendo esta cosa el señor gouernador y todos los otros christianos: el señor Hernando piçarro pidio por merced al gouernador su hermano que le diesse licencia para yr a aquella mezquita sobredicha: porque el queria ver aquel falso dios, o mas verdaderamente demonio, pues que tenia tanto oro: y el gouernador les dio licencia: y lleuaron algunos sacristanes con quien el demonio podia medrar muy poco. El señor gouernador y todos los que con el quedamos nos viamos cada dia en mucho trabajo: porque aquel traydor de Atabalipa hazia continuamente venir gente sobre nosotros: y venian: y no osauan allegar. ¶ Llego el señor Hernando piçarro a vn pueblo que se dezia Guamachuco: y alli hallo oro que trayan por rescate del cacique, que serian cien mil castellanos Alli escriuio Hernando piçarrro al gouernador que embiasse por aquel oro porque fuesse a buen recaudo: el gouernador embio tres de cauallo que viniessen con ello: y en

XEREZ *C2r2:*

El capitan Hernando piçarro se partio de Caxamalca bispera de los reyes del año de mil y quinientos y treynta y tres.

ESTETE *C2v2:*

Miercoles dia de la Epiphania (que se dize vulgarmente la fiesta de los tres reyes magos a cinco de enero del año mil y quinientos y treynta y tres partio el capitan Hernando piçarro del pueblo de Caxamalca con veynte de cauallo y ciertos escopeteros:

con il signor Hernando Pizarro. & vidi la testa con la pelle, la carne secca, & li suoi capegli, & hauea li denti serrati, & tra quelli hauea vna cannella d'argento, & in cima de la testa teneua vna coppa d'oro appiccata, *con vn buco che entraua ne la testa.* quando li veniua in memoria de la guerra che suo fratello li haueua fatta, metteuano *gli schiaui*[1] la chicha in quella coppa, laqual vsciua per la bocca, & per la cannella donde beuea Atabalipa. In questi giorni fu portato certo oro, & di gia il signor Gouernator haueua inteso come in quella terra era vna moschea molto ricca, nella quale era molto piu oro di quello ch'el Cacique li hauea promesso. perche tutti li Caciqui di quelli 9 r
paesi adorauano in quella. Et similmente il detto Cusco, liquali veniuano à intendere quello che haueuano à fare. & molti di del anno veniuano ad vn' Idolo che hauean fatto, & gli dauan da bere in vno smeraldo concauo.[2] Sapendo questa cosa il signor Gouernatore & tutti li altri christiani *che vi erano presenti,* il signor Hernando Pizarro dimandò di gratia al Gouernator suo fratello, che li desse licentia di poter andar a quella moschea: perche voleua veder quel falso iddio, o per dir meglio quel demonio, poi che hauea tanto oro. Il Gouernator li dette licentia, & menorono alcuni spagnuoli[3] con loro, con liquali il demonio poteua aiutarsi molto poco. *& questo fu l'anno .1533.* Il signor Gouernatore & tutti quelli che restammo, ci trouauamo ogni giorno in molto trauaglio: perche il traditor di Atabalipa faceua continouamente venir gente contra di noi, quali veniuano, ma non bastaua lor l'animo di assaltarci. Arriuò il signor Hernando Pizarro ad vn luogho detto Guamachuco, & vi trouò oro che portauano per riscatto del Cacique *Atabalipa:* che poteua esser da cento mila castigliani *d'oro,* & scrisse al Gouernatore che mandasse per quello, oro, accioche venisse con buona guardia. Il Gouernatore mandò tre huomini à cauallo che lo accompagnassero, à quali arriuati consegno l'oro, &

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[1] Original: gli'schiaui. 1545: les esclaues estoient faitz à luy verser la chiche en celle couppe.

[2] 1545: vn idole forgé de leur main, auquel ilz presentoient à boire en vn vase d'esmeraude creuse.

[3] 1545: quelques Espagnolz, contre lesquelz ce diable tresorier eust eu peu de resistence.

llegando les entrego el oro y se passo adelante camino de la mezquita: los de cauallo fueron con el oro a donde el gouernador estaua: y en el camino les acontecio vn desastre: que los compañeros que trayan el oro riñeron sobre ciertas pieças que faltauan de oro: y el vno corto vn braço al otro: que no lo quisiera el governador por todo el oro Estando en aquel pueblo quarenta dias sin esperança de socorro: vino Diego de Almagro con harta gente en nuestro socorro. Delqual nos auian dicho que queria poblar en puerto viejo: mas quando supo las buenas nueuas, como es fiel seruidor del Emperador, vino luego en nuestro socorro. El cacique dixo al gouernador que el oro no podia venir tan presto: que como el estaua preso, no hazian los indios lo que mandaua: que embiasse tres christianos al Cuzco, que estos traerian mucho oro: que desguarnecerian ciertas casas que estauan chapadas con oro: y que traerian mucho oro que auia en Xauxa: y que podian yr seguros: que toda la tierra era suya. El gouernador los despacho encomendando los a Dios. y lleuaron mucha gente que los lleuauan en hamacas: y eran muy bien seruidos Y legaron a vn pueblo que se dize Xauxa, donde estaua vn gran hombre capitan de Atabalipa. este era el que prendio al Cuzco: y tenia todo el oro en su poder: y dio a los christianos treynta cargas de oro. ellos lo estimaron poco: y mostrando[1] que tenian poco temor del, le dixeron que era poco: el les mando dar otras cinco cargas de oro: esto embiaron a donde quedaua el señor gouernador con vn negro que lleuauan. y ellos passaron adelante: y

XEREZ *C2r1:*

Veynte dias eran passados de diziembre del sobredicho año quando llegaron a este pueblo ciertos indios mensageros del pueblo de sant Miguel con vna carta en que hazian saber al gouernador como auian arribado a esta costa a vn puerto que se dize Cancebi junto con Quaque seys nauios en que venian ciento y cincuenta españoles y ochenta y quatro cauallos los tres nauios mayores venian de Panama en que venia el capitan Diego de Almagro con ciento y veynte hombres: y las otras tres carauelas venian de Nicoragua con treynta hombres: y que venian a esta gouernacion con voluntad de seruir en ella:

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[1] Original: mostando.

passo auanti al camino della moschea, & coloro si ritornorono al Gouernatore: & nel camino accadde che li compagni che portauano l'oro vennero insieme alle mani per alcuni pezzi d'oro, & vno taglio vn braccio a l'altro. Ilche non haueria voluto il Gouernatore per tutto il detto oro. Stando nella citta *di Caxamalca* quaranta giorni *il Gouernator* senza speranza di aiuto, venne Diego di almagro, con *cento & cinquanta spagnuoli* in nostro soccorso: dalquale intendemmo che voleua far habitare vn porto vecchio *detto Cancebi,* ma come intese che noi haueuamo trouato tanto oro, come fedel seruitor del Imperadore, venne in nostro soccorso. Il Cacique *Atabalipa in questo tempo* disse al Gouernatore che l'oro non poteua venire cosi presto, perche stando lui prigione gli indiani non lo vbidiuano: & che mandasse tre christiani al *paese* Cusco, che questi portariano molto oro, & disforniriano certe case che di lame d'oro erano coperte. portarianne[1] anchora molto che si trouaua in Xauxa, & che poteuano andare sicuri, perche tutto il paese era suo. Il Gouernatore vi mandò huomini raccomandandogli à Dio liquali *christiani* menorono assai 9 v
indiani che li portauano in hamacas *quale è à modo di vna lettica,* & erano molto ben seruiti, & arriuorono al luogho detto Xauxa, doue staua vn grande huomo capitano di Atabalipa, qual era quello che prese il Cusco, & hauea tutto l'oro in suo potere. Et dette alli christiani trenta cariche d'oro, *delle quali ciascuna pesaua libre cento.* & loro ne fecero poco conto, & mostrando che haueano poca paura di lui, gli dissero che era poco: & lui ordinò che li fussino dati altre cinque cariche d'oro, ilqual oro mandorono doue staua il signor Gouernator, per vn *suo* negro che haueano menato seco. & li detti volsero andar auanti, & arriuorono alla citta del Cusco, doue trouoro-

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[1] 1556, 1565, 1606: ne portariano.

allegaron al pueblo del Cuzco: alli hallaron vn capitan de 5 v Atabalipa que se dize Quizquiz, que en su lengua quiere dezir baruero. Este estimo muy poco a los christianos, aunque se marauillo mucho dellos: y ouo christiano que se quiso llegar a el a dar le de estocadas: y no oso por la mucha gente que tenia. Dixo les aquel capitan que no le pidiessen mucho oro: que si no quisiessen dar por rescate al cacique, que el lo yria a sacar. y luego los embio a vnos bohios del sol en que ellos adoran. Estos bohios estauan de la parte que sale el sol chapados de oro de vnas planchas grandes: y quanto mas les venia dando la sombra del sol tenian mas baxo oro en ellos. Los christianos fueron a los bohios: y sin ayuda ninguna de indios (porque ellos no les querian ayudar porque era bohio del sol, diziendo que se moririan) los christianos determinaron con vnas barretas de cobre de desguarnecer estos bohios: y assi los desguarnescieron segun por su boca ellos lo dixeron. y mas desto juntaron por el pueblo muchos cantaros de oro, y los truxeron a los christianos, que los lleuassen por rescate de su señor En todas aquellas casas del pueblo dizen que hauia tanto oro que era cosa de marauilla. En otra casa entraron donde hallaron vna silla de oro donde hazian sus sacrificios. esta silla era tan grande que pesaua diez y nueue mil pesos: y se podian echar dos hombres en ella. En otra casa muy grande hallaron muchos cantaros de barro cubiertos con hoja de oro: que pesauan mucho. no se los quisieron quebrar, por no enojar a los indios. en aquella casa estauan muchas mugeres: y estauan dos indios en manera de embalsamados: y junto con ellos estaua vna muger biua con vna maxcara de oro en la cara ventando con vn auentador el poluo y las moscas: y

Xerez B8v2:

El Cuzco viejo dexo por señor de la prouincia de Guito apartada del otro señorio principal a atabaliba. y el cuerpo del Cuzco esta en la prouincia de Guito donde murio: y la cabeça lleuaron a la ciudad del cuzco. y lo tienen en mucha veneracion con mucha riqueza de oro y plata: que la casa donde esta es el suelo y paredes y techo todo chapado de oro y plata entretexido vno con otro: y en esta ciudad ay otras veynte casas las paredes chapadas de vna hoja delgada de oro por de dentro y por de fuera.

no vn capitano di Atabalipa, che si chiamaua Quizquiz, che vuol dire in quella lingua Barbiero. Costui fece poca stima delli christiani, anchora che si marauigliasse non poco di loro (& per questo fu vno delli nostri che volse approssimarsi à lui, & dargli delle ferite, pure non lo fece per la molta gente che teneua) *allora* il capitano disse loro che non li dimandassero molto oro, & che se non voleuano restituir il Cacique per quel tanto che gli daua, che lui lo anderebbe à tor di sua mano: & subito gli in vio[1] ad vno tempio del Sol che loro adorano. Questo tempio era volto à leuante, coperto di piastre d'oro. Li christiani andorono al detto tempio, & senza aiuto di alcuno indiano, perche loro non gli voleuano aiutare, essendo quello tempio del Sol, dicendo che moririano: li christiani determinarono con alchuni picchetti di rame disfornir quel tempio, & cosi lo spogliorono. (secondo che poi di bocca loro ci dissono.) Et oltra questo furono ragunate anchora molte olle o pignatte d'oro, *con lequali vsano cucinare in quel luogho*, & portate alli christiani per riscatto del suo signore *Atabalipa.* In tutte le case doue habitano dicono che era tanto oro che era marauiglia. In vna casa introrono, doue trouorono vna sedia d'oro, doue[2] fanno li suoi sacrificii. Questa sedia era tanto grande che pesaua .19. mila pesi, nella quale poteuan seder duoi huomini. In vn' altra casa molto grande, *nellaquale giaceua morto il Cusco vecchio, il pauimento della quale, & li muri eran coperti di piastre d'oro & d'argento*, trouorono molti cantari, *ouer giarre* di terra coperte di lame d'oro che pesauano molto, & non gli volseno rompere per non far dispiacere alli indiani. in laqual casa erano molte donne, & eranui duoi Indiani *morti*, 10 r à modo di imbalsimati: appresso delli quali staua vna donna, con vna maschera d'oro sul viso, facendogli vento con vno ventaglio per la poluere, & per le mosche. & li detti indiani morti haueuano in mano vn

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[1] 1535: in vio. 1556, 1565: in vio. 1606: inuiò.

[2] 1556: Entrorono: in vna casa doue fanno li loro sacrificij, doue trouorono vna sedia d'oro. 1565: Entrorono in vna casa doue fanno etc. 1606: Entrorono in vna casa, doue fanno li loro sacrificij, doue trouarono vna sedia d'oro. 1535: same as 1534. 1545: vne chaire d'or dediée à leurs sacrifices.

ellos tenian en las manos vn baston muy rico de oro. La muger no los consintio entrar dentro, sino se descalçassen: y descalçandose fueron a ver aquellos bultos secos: y les sacaron muchas pieças ricas: y no se las acabaron de sacar todas: porque el cacique Atabalipa les auia rogado que no se las sacassen diziendo que aquel era su padre el Cuzquo: y por esso no osaron sacar le mas Assi cargaron su oro: que el capitan que alli estaua les dio el aparejo que pudo. Los christianos hallaron en aquel pueblo tanta plata, que dixeron al governador que hauia alli vna casa grande quasi llena de cantaros y tinajas grandes y vasos y otras pieças muchas: y que mucho mas truxeran, sino por no se detener alli mas: y porque estauan solos: y mas de dozientas y cincuenta leguas de los otros christianos. Cerrada la casa y las puertas della: y puesto vn sello por su magestad y por el governador Francisco piçarro: y assi mesmo dexaron guarda de indios: y pusieron señor en el pueblo, que assi les era mandado. y tomaron su camino con el oro: en que trayan pieças muy hermosas: entre las quales auia vna fuente muy grande de oro muy fino hecha de muchas pieças: pesaua esta pieça mas de doze mil pesos. estas y otras muchas cosas truxeron

¶ Dexo de hablar en estos que venian por su camino: y dire del señor Hernando piçarro que yua camino de la mezquita: y llego alla con mucho trabajo: porque pensaron no lleuar alla cauallo ninguno por falta de herrage y del mal camino. Mas el señor Hernando piçarro mando hazer a los

Estete *C3r1/2:*

en medio del camino ay vn rio grande muy furioso: tiene dos puentes juntas hechas de red desta manera que sacan vn gran cimiento desde el agua: y lo suben bien alto: y de vna parte del rio a otra ay vnas maromas hechas de bexucos a manera de bimbres tan gruessas como el muslo: y tienen las atadas con grandes piedras: y de la vna a la otra ay anchor de vna carreta: y atrauiessan rezios cordeles muy texidos: y por debaxo ponen vnas piedras grandes paraque apesgue la puente. Por la vna destas passa la gente comun: y tiene su portero que pide portazgo: y por la otra passan los señores y sus capitanes Esta esta siempre cerrada y abrieron la para que passasse el capitan y su gente: y los cauallos passaron muy bien.

Estete *C3r1:*

Esta jornada fue muy mala porque auia vna baxada de escaleras hechas de piedra muy agra y peligrosa para los cauallos.

baston molto ricco d'oro. la donna non volse che intrassero dentro, se non si discalzauano, & discalzandosi andorono à veder quelli corpi secchi, & leuorono loro datorno molti pezzi d'oro, ne del tutto gli spogliorono: perche il Cacique Atabalipa gli hauea pregati che non gli spogliassero *del tutto*, dicendo che quel era suo padre, il Cusco *vecchio*, & per questo non ne volsero tor piu: & cosi caricorono il suo oro: & il capitan che vi era li dette tutte le cose necessarie per condurlo via. Li christiani trouorono in quel loco tanto argento che disseno al Gouernatore che vi era vna casa grande quasi piena di cantari, & tinacci grandi, & vasi, & altre pezze molte. & che molto piu ne hauerian portato ma temeuano di non dimorar troppo, perche erano soli, & piu di dugiento & cinquanta leghe lontani dalli altri christiani. *ma dissero che haueuan* serrato la casa & le porte di quella, & messoui vn sigillo per la Maesta *del Imperadore*, & per il Gouernator Francesco Pizarro, & ordinatoui guardie di indiani, & fatto vn signore in quel luogho come gli era stato comandato. preseno il suo camino con le pezze del oro bellissime che portauano: tra lequali era vna fontana grande d'oro fatta di molti pezzi. pesaua questa piu di dodici mila pesi. questa & molte altre cose portorono.

Lascio di parlare di costoro che veniuano per il suo camino, & dirò del signor Hernando Pizarro, ilqual andaua alla volta della moschea. *Nelqual viaggio che fu di molte giornate, trouorono molti fiumi, sopra ciascuno delli quali, sempre trouorono duoi ponti, fatti vicini l'uno all'altro, in questo modo. haueuan fatto nel mezzo del fiume vna pila, laquale appariua molto sopra l'acqua, per sostegno del mezzo del ponte, perche da vna parte & da l'altra del fiume erano appiccate corde fatte di stroppe di salcio, grosse come vn ginocchio: lequali alle riue erano legate à grossi sassi discosto l'una da l'altra la larghezza d'un carro. à queste per trauerso eran legate corde forti & ben tessute, di cotone. & perchel ponte stesse forte, appiccauano dalla parte di sotto, à queste corde sassi molto grandi. vno di questi ponti seruiua alla gente comune & staua sempre aperto: l'altro alli signori & capitani, & questo staua sempre* 10 v *serrato, & fu aperto quando passò il signor Hernando Pizarro,* & arriuò con molto trauaglio: perche pensorono non condur mai alcuni caualli, per mancamento di ferrature per il mal camino, *perche passorono per molte montagne, la strada de lequali era fatta a mano come vna scala:* ma il signor Hernando comandò alli indiani che facessino

indios herraduras de oro y de plata y clauos: y assi lleuaron sus cauallos al pueblo donde la mezquita estaua: elqual pueblo es mayor que Roma: en aquella mezquita estaua el diablo que hablaua con los indios en vna camara muy escura y suzia como el es. Alli hallo muy poco oro: porque todo lo tenian escondido: y hallaron vn hoyo muy grande de donde lo auian sacado: y los assientos de los cantaros que auian lleuado: de manera que nunca lo pudieron descubrir. En la mesma casa vnas indias que la guardauan le dieron vn poco de oro que lo tenian por ay echado. assi mesmo sacaron a los christianos de vnos muertos que estauan alli mucho oro:

ESTETE *C3v2/C4r1:*

El estaua en vna buena casa bien pintada en vna sala muy escura e hidionda muy cerrada: tienen vn ydolo hecho de palo muy suzio: y aquel dizen que es su dios el que los cria y sostiene y cria los mantenimientos. a los pies del tenian ofrecidas algunas joyas de oro. tienen le en tanta veneracion, que solos sus pages y criados que dizen que el señala essos le siruen: y otro no osa entrar ni tienen a otro por digno de tocar con la mano en las paredes de su casa. Aueriguose que el diblo se reuiste en aquel ydolo: y habla con aquellos sus aliados, y les dize cosas diabolicas que manifiesten por toda la tierra A este tienen por dios: y le hazen muchos sacrificios. Vienen a este diablo en peregrinacion de trezientas leguas con oro y plata y ropa: y los que llegan van al portero y piden su don: y el entra, y habla con el ydolo, y el dize que se lo otorga Antes que ninguno destos sus ministros entre a seruir le, dizen que ha de ayunar muchos dias: y no se ha de allegar a muger. Por todas las calles de este pueblo y a las puertas principales del y a la redonda desta casa ay muchos ydolos de palo y los adoran a imitacion de su diablo. Ha se aueriguado con muchos señores desta tierra que desde el pueblo de Catamez que es al principio deste gouernamiento toda la gente desta costa seruia a esta mezquita con oro y plata: y dauan cada año cierto tributo: tenian sus casas y mayordomos adonde echauan el tributo: adonde se hallo algun oro y muestra de auer alçado mucho mas: aueriguosse con muchos indios hauerlo alçado por mandado del diablo. Muchas cosas se podrian dezir de las ydolatrias que se hazen a este ydolo: mas por euitar prolixidad no las digo: mas de quanto se dize entre los indios que aquel ydolo les haze entender que es su dios: y que los puede hundir si le enojan, y no le siruen bien: y que todas las cosas del mundo estan en su mano. Y la gente estaua tan escandalizada y temerosa de solamente auer entrado el capitan a ver le: que pensauan que en yendo se de alli los christianos los auia de destruyr a todos.

ferrature[1] d'oro & d'argento, & cosi li chiodi, & in questo modo condussero gli suoi caualli al luogho doue era la moschea, à vna citta laquale è maggior di Roma[2] *detta Pachalchami.* nellaqual moschea è vna camera molto brutta & sporcha, doue è vn idolo *fatto di legno molto brutto, ilqual dicono esser lo Dio loro, & che questo fa nascere tutto quello di che viuono. alli piedi del qual tengono offerte alcune gioie, massime smeraldi legati in oro, & hannolo in tanta veneratione, che voglion che sol quelli lo vadino à seruire, che da quello (come dicono) son chiamati: & dicono che nessuno è degno di toccarlo con mano, ne anchora li muri della casa sua. Non è da dubitar che il diauolo non entri in quel idolo, & parli con quelli suoi ministri, & dichi loro quel che hanno à dir per il paese. Vengono a questo idolo con grandissima diuotione gli indiani, di lontano trecento leghe, & gli offeriscono oro & argento & gioie. & subito che arriuano, presentano il dono al portinaro, & lui entra dentro, & parla con l'idolo, & porta fuora la risposta. Auanti che alcun ministro vadi à seruirlo, bisogna ch'el sia puro, & casto, & che digiuni, & non tocchi donna. Tutto il paese di Chatamez, che è li intorno è deuotissimo di questa moschea: & per questo vi portano ogni anno tributo, & l'idolo fa loro intendere che lui è loro Iddio: & che tutte le cose del mondo sono nelle man sue: & che niente adiuiene alli huomini che non sia di sua volonta. per ilche glindiani della moschea & della citta di Pachalchami erano in grandissima paura, perche il capitan Hernando Pizarro con li spagnuoli, senza alcun rispetto erano entrati à vederlo, & per questo dubitauano gli indiani, che dapoi vsciti li spagnuoli l'idolo non gli distruggesse.* Di questa moschea cauorono molto poco oro, perche l'haueuano tutto ascoso. & trouorono vna caua molto grande, donde haueuano tratto l'oro, & li luoghi doue stauano li cantari che gli haueano leuati, di sorte, che mai poterono trouar doue l'oro fusse. In vna altra casa viddero vn poco di oro ad vna indiana che guardaua la casa, che l'hauea gittato *in terra.* trouorono 11 r similmente[3] li christiani alquanto oro appresso certi morti che

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[1] 1545: des fers d'or & d'argent.

[2] 1545: vne ville plus grande que Rome nommée Pachalchami. Map of 1545: PACHALCHAMI ville plus grande que Paris.

[3] 1556, 1565, 1606: trouorono similmente certi morti. 1535: same as 1534.

y vnos caciques de Chicha le dieron oro. de manera que le dieron en todo quarenta mil pesos. Estando alli le embio Chiliachima (que era el capitan que prendio al Cuzquo) diziendo que tenia mucho oro para lleuar por rescate de su señor Atabalipa: y que el se partiria de aquel pueblo de 6 r Xauxa a donde estaua: y que se juntaria con el capitan Hernando piçarro: y que ambos a dos yrian a ver al gouernador. Hernando piçarro se partio pensando que era verdad lo que los indios le dezian: mas andando quatro o cinco jornadas, supo que no venia el capitan y assi determino con la poca gente que lleuaua boluer al real del capitan que estaua con gran poder de gente. y assi boluio y dixo al capitan que fuesse a ver al señor gouernador, y a su cacique Atabalipa. el dixo que no queria salir de alli: porque assi lo auia mandado su señor Atabalipa. Hernando piçarro le dixo que sino queria venir, que lo lleuaria por fuerça. y assi puso en orden la poca gente que lleuaua: porque el estaua en vna plaça grande:[1] alli pensaua aunque era la gente mucha vengar se dellos: porque los que yuan con el eran buenos hombres. El capitan indio quando vio aquella gente puesta en concierto, determino de venir con el señor Hernando piçarro. y assi vino donde estaua el señor gouer-

ESTETE *C5r2:*

Este pueblo de Xauxa es muy grande: y esta en vn hermoso valle: es tierra muy templada: passa cerca del pueblo vn rio muy poderoso: es tierra abundosa: el pueblo esta hecho a la manera de los de España y las calles bien traçadas. a vista del ay otros pueblos subjectos a el.

ESTETE *C4v2:*

¶ *Viernes a catorze dias del dicho mes de Março partio el capitan con su gente de pie y de cauallo del dicho pueblo de Pombo para yr a Xauxa: y este dia fue a dormir a vn pueblo llamado Xacamalca seys leguas de tierra llana del pueblo de donde partio. Ay en el campo vna laguna de agua dulce que comiença de junto a este pueblo: y tiene de circuito ocho o diez leguas, toda cercada de pueblos: y cerca della ay muchos ganados y ay en ella aues de agua de muchas maneras y pescados pequeños. En esta laguna tuuo el padre de Atabaliba y el muchas*

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[1] Original: end of line 8, "grande"; beginning of line 9, "de:".

erano *in detta moschea,* tal che non poterono hauerne piu di *trenta mila pesi.* & da vn Cacique di Chicha ne hebbero tanto[1] che arriuorono alla somma di quaranta mila pesi. Et stando quiui gli mandò Chilicuchima, che era il capitan che prese il Cusco, *nuntii,*[2] & fecegli intendere che hauea molto oro per portar per riscatto del suo signore Atabalipa, & che si partirebbe da quel luogho di Xauxa, *quale è vna citta molto grande, fondata in vna bella valle, & ha l'aere molto temperato,* & che si accompagnaria con il signor Hernando Pizarro, & che insieme anderiano à veder il Gouernatore. Hernando Pizarro si parti pensando che fusse la verita quel che glindiani diceuano, ma essendo andato quattro, o cinque giornate seppe che non veniua il capitano, & delibero con la gente che haueua, andarsene al luogho del Capitano: che era con gran gente, & cosi fece. & *trouatolo* gli disse che venisse à veder il signor Gouernatore, & il suo Cacique Atabalipa. lui rispose che non voleua partirsi di quel luogho, essendogli stato cosi comandato dal suo signore. *Allhora* Hernando Pizarro gli disse che se non voleua venire, lo menerebbe per forza, & misse in ordine quella pocha gente che hauea, perche era in vna piazza grande, & pensaua, anchora che fussero molti, di vendicarsi di loro, perche quelli che erano con lui erano valenti huomini. Il capitan indiano quando vidde quella gente messa in ordine, deliberò andar con lui. *Ilquale partito, auanti che arriuasse doue staua il signor Gouernator in Caxamalca con il Cacique Atabalipa, sei leghe, lontano, trouò vn lago d'acqua dolce: che era di circuito circa dieci leghe con le riue tutte piene di arbori verdissimi, & tutto habitato intorno da Casali di indiani, quali sono pastori con pecore di diuerse sorti, cioè alcune piccole, come le nostre, & altre tanto grandi che le adoperano in portar le cose che gli fa di bisogno, per somieri. In questo lago sono vccelli di diuerse sorti, & similmente pesci. dalquale*

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[1] 1545: il est bien vray qu'en la maison d'une Indoyse noz gens trouuerent quelque quantité d'or caché en terre: à l'entour de certains corps gisans en ceste eglise feirent aussi leur main d'enuiron trente mille liures puis en recouurerent du Cacique de Chica peu s'en fallut de dix mille liures.

[2] 1556, 1565, 1606: messi.

nador. Al cacique Atabalipa le peso mucho de la venida de su capitan: mas como era muy astuto, dio a entender que le plazia. El gouernador le pregunto por el oro del Cuzco: que aquel capitan era el que lo auia prendido: el respondio segun Atabalipa le auia auisado: que ningun oro tenia, que todo lo auian traydo. Todo lo que dezia era mentira Y apartando lo hernando de soto le amenazo que sino dezia la verdad que lo quemaria: el le respondio lo que antes auia dicho: y luego hincaron vn palo, y lo ataron a el: y truxeron mucha leña y paja, diziendo que sino dixesse la verdad que lo quemarian. El mando llamar a su señor: el qual vino con el gouernador: y hablo con su capitan que estaua atado. El capitan le dixo que queria dezir la verdad a los christianos: porque sino la dixesse lo quemarian. Atabalipa le dixo que no dixesse nada. que aquello que hazian, no era sino para le poner espanto: que no osarian quemar le. y assi le preguntaron otra vez por el oro, y no lo quiso dezir. mas

balsas traydas de tumbez para su recreacion. Sale desta laguna vn rio que va al pueblo de Pombo: y passa por la vna parte del muy sesgo y hondable: y pueden venir por el a desembarcar a vna puente que esta junto al pueblo. los que passan pagan portazgo como en España. Por todo este rio ay muchos ganados: pusosse le por nombre Guadiana, porque le parece mucho.

ESTETE *C6r1:*

Aqui se ha visto vna cosa que no se ha visto despues que las indias se descubrieron: y aun entre españoles es bien de notar: que al tiempo que Chilicuchima entro por las puertas donde estaua preso su señor tomo a vn indio de los que consigo lleuaua y vna carga mediana y echose la encima y con el otros muchos principales de aquellos que consigo lleuaua: y assi cargado el y los otros entro donde su señor estaua: y quando lo vio alço las manos al sol, y dio gracias porque se lo auia dexado ver: y luego con mucho acatamiento llorando se llego a el y le beso en el rostro y las manos y los pies: y assi mesmo los otros principales que venian con el. Atabaliba mostro tanta magestad, que con no tener en todo su reyno a quien tanto quisiesse: no le miro a la cara: ni hizo del mas caso que del mas triste indio que viniera delante del. y esto de cargar se para entrar a ver a Atabaliba es cierta cerimonia que se haze a todos los señores que han reynado en aquella tierra.

nasce vn fiume bellissimo, ilqual si passa con vn ponte fabricato nel modo detto di sopra, doue stanno certi indiani à torre vn certo tributo da tutti quelli che passano. Giunti à Caxamalca doue era il Gouernatore & Atabalipa, il capitano chilicuchima auanti che entrasse nella stanza doue sedeua il Cacique Atabalipa suo signore, prese da vn indiano di quelli che lui menaua seco, vna carica mezzana, & se la messe 11 v *sopra le spalle, & il medesimo fecero tutti gli altri principali che lo seguitauano, & entrati dentro, subito come lo vidde alzò tutte due le mani verso il sole, ringratiandolo che li hauesse fatto veder il signor suo, & subito piangendo si buttò in terra, & con molta riuerentia pian piano si accostò à lui, & gli bacio le mani, & gli piedi, & il simil fecero gli altri indiani principali. Atabalipa allhora mostro grandissima maesta: & anchora che sapesse, che non hauea huomo in tutto il suo paese che lo amasse piu de Chilicuchima: non lo volse però guardar ne la faccia, ma stette con vna grauita ammirabile,*[1] *ne fece alcun atto o dimostratione, non altrimenti che se gli fusse venuto auanti il piu vil indiano suo suddito.*[2] *Questo atto di caricarsi le spalle quando vanno à veder gli suoi signori dimostra vna gran riuerentia che gli hanno.* Questo Cacique Atabalipa non hebbe grata la venuta del suo capitano, ma essendo molto astuto: finse di hauerne hauuto piacere. Il Gouernatore gli dimandò de l'oro del Cusco perche quel Capitano era quello che lhauea preso. Quello rispose si come Atabalipa lo hauea auisato, che non haueano altro oro, & che *quello che haucano,* tutto lo haueano portato. tutto quel che diceua era falso: & tirandolo da parte Hernando di Soto, lo minacciò, che se non diceua la verita lo abbruciarebbeno: lui gli rispose quel che prima hauea detto, donde subito ficcorono vn palo, alqual lo legorono, & portorono molte legne & paglia, dicendo pur, che se non dicesse la verita lo abbrucerebbeno. *Chilicuchima* fece chiamar il suo signore, ilqual venne[3] con il Gouernatore, & parlo con lui, & *finalmente* gli disse che voleua dire la verita alli Christiani, perche non dicendola lo abbruciarebbeno. Atabalipa gli disse che non dicesse cosa alcuna, perche esti tutto quello faceuano per farli paura: che non hariano ardimento di abbruciarlo, & cosi gli dimandorono un'altra

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[1] 1556, 1565, 1606: mirabile.

[2] 1545: au plus simple paysan de toute l'Inde.

[3] 1545: Adonc feit appeller son maistre, lequel le gouuerneur luy amena.

luego que le pusieron vn poco de fuego: dixo que le quitassen aquel cacique su señor de delante, porque el le hazia del ojo que no dixesse la verdad: y assi se lo quitaron de alli: y luego dixo que por mandado del cacique el auia venido tres o quatro vezes con mucho poderio de gente sobre los christianos: y como los christianos lo sabian: el mesmo Atabalipa su señor le mandaua boluer: por miedo que los christianos no los matassen: Assi mesmo le hizieron otra pregunta, que donde estaua el oro del Cuzco viejo. el les dixo que en el mesmo pueblo del Cuzco estaua vn capitan llamado Quizquiz y que este capitan tenia todo el oro: porque ninguno osa llegar a el: que todauia aunque es muerto hazen su mandado tan enteramente como si fuesse biuo: y assi le dan a beuer: y derraman aquel vino que le auian de dar a beuer alli acerca de donde el cuerpo del cuzco viejo esta: Assi mesmo dixo aquel capitan indio a los christianos que en aquel pueblo de abaxo donde el cacique Atabalipa su señor tenia assentado su real estaua vn toldo muy grande en el qual el cacique tenia muchos cantaros y otras diuersas pieças de oro. Estas y otras cosas dixo aquel capitan indio a los christianos en las quales[1] yo no me halle presente: Luego lleuararon aquel capitan indio a la casa del señor Hernando piçarro: y pusieron diligentemente guarda sobre el: porque assi conuenia que se pusiesse: porque mas obedescia la mayor parte de la gente al mandado deste capitan que al del mesmo cacique Atabalipa su señor, porque era muy valiente hombre en la guerra: y auia hecho mucho mal por toda aquella tierra: y assi estaua aquel capitan muy enojado contra el cacique Atabalipa su señor: diziendo que por su causa le auian maltratado: El cacique no le embiaua de comer ni otra cosa alguna a causa del mucho enojo que contra el tenia: por lo que auia dicho: mas el señor capitan que lo tenia en su casa le daua bien de comer y assi le hazia seruir y dar le todo lo que auia menester: y aunque estaua assi medio quemado muchos de aquellos indios le venian a seruir porque eran sus
6 v criados. Y este capitan era natural de vna prouincia que

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[1] Original: qules.

volta de l'oro, & lui non lo volse dire. Ma subito che gli missero vn poco di foco *intorno,* disse che menassero via quel Cacique suo signore, perche lui li faceua cenno che non dicesse la verita, & cosi lo menorono via, & subito disse che per comandamento del Cacique *Atabalipa* lui era venuto tre o quattro volte con molta gente per assaltare li christiani, ilqual dipoi ordinaua loro che tornassero in dietro, per paura che conoscendo gli christiani *gli suoi tradimenti* non lo amazzassero. similmente gli dimandorono vnaltra volta doue era l'oro 12 r
del Cusco vecchio: lui gli disse che nel medesimo luogho del Cusco era vn capitan chiamato Quizquiz, & che questo capitano hauea tutto l'oro, perche niuno ardisce accostarsi à lui: che anchora che sia morto, fanno il suo comandamento, cosi integramente come se'l fusse viuo, & cosi gli danno da bere, & spandono *tutto* quel vino che gli vogliono dar a bere li intorno doue il corpo del Cusco vecchio è posto. & similmente disse quel capitano indiano che in quella terra piu abbasso doue il Cacique Atabalipa suo signor hauea alloggiato il suo essercito, era vn padiglion molto grande, nelquale il Cacique hauea molti cantari, *ouer giarre grandi* & altre diuerse pezze di oro *di molte sorti.*[1] Questo & *molte* altre cose disse quel capitano indiano alli christiani *che quiui erano,* lequali io non sapria dire, per non essermi trouato presente. *Poi che costui hebbe cosi detto,* subito lo menorono alla casa del signor Hernando Pizarro, & gli faceuano vna diligente guardia, perche cosi era necessario: imperoche piu vbidiua la maggior parte de la gente al comandamento di questo capitano, che al medesimo Atabalipa suo signore. perche era molto valent'huomo in guerra, & hauea fatto molto male in quella prouincia: & era il detto capitano molto sdegnato contra Atabalipa suo signore, dicendo che per sua causa lo haueano mal trattato. il Cacique non gli mandaua da mangiare ne altra cosa alcuna, per causa del molto sdegno che contra lui teneua, per quel che haueua detto. ma il signor capitano che l'hauea in casa gli daua ben da mangiare & lo faceua seruire & dauagli quanto gli faceua di bisogno, & anchor che fusse cosi mezzo abbruciato, molti di quelli Indiani lo andauano a seruire, perque erano suoi familiari. & questo

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[1] 1545: auquel gisoit grande quantité de vaisselle, & d'autres pieces diuerses d'inestimable valeur.

se dize Guito: de la qual el mesmo Atabalipa era señor. Esta tierra es muy llana y rica: los hombres della son muy valientes. con esta gente conquistaua Atabalipa la tierra del Cuzco. y della salio el cuzco viejo quando començo a señorear todas aquellas tierras. Dixo el cacique Atabalipa que hauia muchas casas deputadas de oro y plata: y que el oro de las minas era menudo: porque las minas de collado eran de aquel cabo del Cuzco: y eran mas ricas, porque sacauan dellas el oro en granos grandes, y no se lauaua el oro: mas del rio lo sacauan en granos. ❡ Dexo de hablar en esto, y dire de los christianos que vinieron del Cuzco: los quales entraron por el real del gouernador con mas de ciento y nouenta indios cargados de oro: trayan veynte cantaros y otras pieças grandes que auia pieça que la trayan doze indios. assi mesmo truxeron otras pieças que sacaron de las casas: de plata poca truxeron porque assi se lo mando el gouernador, que no truxessen plata sino oro: porque el cacique se quexaua

XEREZ *B8v2:*

La plata sacan en la sierra con poco trabajo: que vn indio saca en vn dia cinco o seys marcos: laqual sacan embuelta con plomo y estaño y piedra sufre: y despues la apuran: y para sacar la pegan fuego a la sierra: y como se enciende la piedra sufre cae la plata a pedaços.

capitano era natiuo di vna prouincia chiamata Guito, della qual il medesimo Atabalipa era signore. Questo paese è molto piano & ricco: gli huomini sono molto valenti. con queste genti conquistò Atabalipa la terra del Cusco.[1] Della qual gente vsci il Cusco vecchio, quando cominciò à signoreggiare tutta quella prouincia. *In su questo ragionamento* il Cacique Atabalipa disse che hauea molte case deputate *à fonder* lo oro & l'argento.[2] & che l'oro de le minere *del piano* era minuto, perche le mine del paese del monte erano[3] di quelle bande del Cusco,[4] & erano piu ricche perche cauano di quelle l'oro in maggiori grani, & non bisognaua lauarlo, ma lo ricoglieuano nel[5] fiume *lauato, &* 12 v *come in alchune montagne cauano l'argento con poca fatica, & che vn huomo ne caua in vn giorno cinque, o sei marche: cauasi mescolato con piombo, stagno, & zolfo, & poi si fa ben netto. Et per cauarlo, gli huomini appiccano fuocho grandissimo nelli monti, & subito che il zolfo è acceso largento scorre in pezzi.* Lascio di parlare piu oltre di questo, dirò delli christiani che vennero dal Cusco,[6] liquali entrorono in Campo del Gouernatore con piu di cento e nouanta indiani carichi d'oro: & ne portorono venti cantari, & altre pezze grandi: che vi era tal pezzo che *con fatica*[7] dodici indiani lo portauano, & similmente portorono altri pezzi che cauorono de le case. Dello argento ne portorono poco, perche cosi comandò loro il *signor* Gouernatore che non portassero argento, ma oro: perche il Cacique si doleua che non

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[1] 1545: par la vertu desquelz Atabalipa auoit acheué toutes ses belles conquestes.

[2] Original: lo oro & 'argento. 1556, 1565: l'oro & l'argento. 1606: l'oro, & l'argento.

[3] Original: era.

[4] 1545: & ne se recueilloit en si groz grain que celuy des montagnes tyrantz sur les riches parties du Perù, aussi qu'il ne le faloit lauer, ains se trouuoit tout net & purifié en la riuiere.

[5] Original: ne fiume.

[6] 1545: ceux qui eurent la commission du Perù. Marginal note, 1545: Notez que tout le pays suget a Atabalipa à esté nommé le Perù du nom de la contrée principalle, & la meilleure icy se prend proprement pour la partie autrement ditte Cusco.

[7] 1545: vint brocz de tel pois & grandeur que douze personnes comployoient soubz le faiz.

que no hallaua indios que truxessen el oro. En los dias passados hauia venido mucho oro: y el gouernador hauia embiado dos hombres al toldo que el capitan auia dicho: y assi truxeron mucho oro: que en vna casa grande hauia en muchas partes montones de oro de diuersos quilates: y pieças menudas: y el gouernador hizo fundir todo el oro menudo: entre lo qual se fundieron algunos granos de oro tan grandes como castañas y otros mayores, y otros de a libra otros de mas peso. y esto digo lo porque yo velaua la casa del oro y los vi fundir. Auia mas nueuecientos tejuelos de oro de minas algunos eran de quilates: muchos dellos se fundieron: Y se hizieron barras: y otros se repartieron entre la gente. En esta casa estauan mas de dozientos cantaros de plata grandes que truxo el cacique: aunque el gouernador no se lo mando: mas auia muchas ollas y cantaros pequeños y otras pieças muy hermosas: y pareceme que aquella plata que yo vi pesar seria cincuenta mil marcos, dos mil mas o menos. Hauia mas en esta casa ochenta cantaros de oro grandes y pequeños y otras pieças muy grandes y vn monton mas alto que vn hombre de aquellas planchas que eran todas finas y de muy buen oro. Esta casa a vna parte y a otra toda era montones de oro y plata. Juntado todo aquel oro y pesando lo presentes los oficiales de su magestad puso el gouernador personas que hiziessen las partes: los quales fueron elegidos por votos de la gente. Y el gouernador embio vn presente a su magestad que fue de cien mil pesos poco mas o menos en ciertas pieças que fueron quinze cantaros y quatro ollas que cabrian a dos arrouas de agua: y otras muchas pieças menudas que eran muy ricas. Y es verdad que despues de ydo el señor capitan vino mucho mas de lo que auia quedado. El se partio: y el señor gouernador hizo las partes: fue cadauna parte de la gente de pie quatro mil y ochocientos pesos de oro: y los de cauallo al doble: sin algunas ventajas que fueron hechas. Dio el señor gouerna-

trouaua indiani che portassero l'oro, delquale alli giorni passati era stato portato, non poca quantita. Haueua il signor Gouernatore mandato duoi huomini al padiglione che il capitano *indiano* gli haueua detto, quali tornorono similmente con assai oro, delquale in vna casa grande haueano in molti luoghi trouati monti grandi di diuerse carattate,[1] & pezze minute. Il gouernator fece fondere tutto il minuto, tra 'l quale furono alcuni grani grandi come castagne, & altri maggiori, & alcuni di peso di libra, & altri di maggior peso, & di questo fo fede, perche io ero guardiano della casa del'oro, & lo vidi fondere, & eraui piu[2] di .90. tegole *come piastre* d'oro di minera, che alcune erano di *buoni* carati, molte sene fonderono, & furon fatte verghe, & altre si spartirono tra la gente. In questa casa erano piu di .200. cantari di argento grandi che hauea fatti portare il Cacique: anchor ch'il Gouernatore non lo hauesse ordinato, ma vi erano molte pignatte & cantari piccoli & altri pezzi molto belli: & parmi che l'argento che io vidi pesare, fusse cinquanta milia marche, poco piu o mancho. Era oltra questo in questa casa ottanta cantari d'oro, tra grandi & piccoli, & altri pezzi molto grandi. Eraui anchora vn monte piu alto d'vn huomo di quelle piastre che eran tutte fini, di molto buon oro: *benche per dire il vero,* in questa casa in tutte le stanze erano monti grandi di oro & di argento. Messe insieme il *signor* Gouernatore tutto quel oro, & fecelo pesare presenti li officiali di sua Maesta.[3] Il che fatto, furono elette persone che facessino le parti *per la compagnia.* Et mandò il Gouernatore vn presente alla Maesta *Cesarea,* che fu 13 r
di cento mila pesi, poco piu, o manco in certe pezze che furono quindici cantari, & quattro pignatte che teneuano duoi secchi d'acqua ciascuna, & altre pezze minute che erano molto ricche, & è la verita, che dapoi partito il signor Capitano fu portato molto piu oro di quello era restato che fu partito. Il signor Gouernatore fece le parti, & toccò a ciascuno fante à pie quattro mila & ottocento pesi d'oro, *che sono ducati .7208.* & à gli huomini à cauallo il doppio, senza altri vantaggi che gli

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[1] 1556: di diuerse carattere, & pezze minute. 1565, 1606: di diuersi caratteri, & pezzi minuti. 1545: car ilz en trouuerent en maintz logis maintz gros monceaux de toutes sortes de pieces tant petites que grandes. 1535: Same as 1534.

[2] 1545: pres de cent liures d'or de mine comme tuylles, dont vne partie estoit de hautz caratz.

[3] 1545: & fust poisé par gens à ce congnoissans.

dor a la gente que auia venido con Diego de Almagro del oro de la compañia antes que se repartiesse veynte y cinco mil pesos de oro: porque tenian alguna necessidad: y a los del pueblo que auia dexado poblado dio dos mil pesos de oro: que los partiessen a dozientos cadauno. Mas dio a todos los que hauian venido con el capitan mucho oro: de manera que a mercaderes daua a dos y a tres copones de oro porque a todos cupiesse parte. y a muchos de los que lo ganaron dio menos de lo que merecian: y esto digo lo porque assi se hizo comigo. Luego huuo muchos que pidieron licencia al señor gouernador para venir se a Castilla. Los vnos por dar relacion a su magestad de la tierra: otros por venir a ver a sus padres, o mugeres. Dio licencia a veynte y cinco compañeros que se viniessen. ❡ En estos dias como supo el cacique que querian sacar oro de la tierra, mando hazer mucha gente por muchas partes: los vnos que viniessen 7 r a los christianos que auian de venir a embarcar se en los nauios: y la otra gente para venir sobre el real: por ver si podria ser libertado: y este era muy gran poder de gente, que venian los mas dellos por fuerça y por temor que tenian. Como el señor gouernador fue desto bien informado: hablo al cacique, y dixo le que porque era tan malo, que hazia venir gente sobre nosotros. Pocos dias antes auian venido a nuestro real dos indios hijos del Cuzco viejo hermanos de Atabalipa de padre y no de madre estos vinieron muy escondidos por miedo de su hermano. Quando el gouernador supo que eran hijos del Cuzco viejo, hizoles mucha honra: porque en la manera dellos se parecia ser hijos de gran señor. Estos dormian junto al gouernador porque no osauan dormir en otra parte por miedo de su hermano. El vno destos era natural señor de aquella tierra: que quedaua despues de la muerte de su hermano. En estos dias vinieron nueuas que la gente de guerra estaua muy cerca: y por esso nos velauamos mucho: y vna noche vinieron indios huyendo de vn pueblo que estaua alli cerca: diziendo que los indios

furon fatti. Dette il signore Gouernatore alla gente che venne con
Diego de Almagro del oro della compagnia auanti che fussero fatte le
parti venticinque mila pesi, perche ne haueuan di bisogno. & à quelli
christiani che erano restati in quel luogho doue hauea fondato il
ridotto *di san Michele*, dette du mila pesi d'oro, accioche lo partissero
che ne toccò dugiento pesi à ciascuno. Et dette a tutti quelli che
erano venuti con il capitano molto oro, di sorte che ad alcuni merca-
tanti dette due, & tre coppe grandi di oro, accioche ciascuno ne hauesse
parte, & a molti di quelli che l'haueano guadagnato dette manco di
quello che lor meritauano. Et questo dico perche a me cosi fu fatto.
Subito ne furono molti, *tra liquali fui io*, che domandorono licentia al
signor Gouernatore per venirsene in Castiglia, alcuni per dar relatione
alla Maesta *del Imperadore* del paese, altri per veder suo padre, &
sua mogliera: & fu data licentia à .25. compagni, quali si partirono.
In questi di come seppe il Cacique che voleuano portar via l'oro del
paese, comando molte genti per molte parti, alcuni che venissero
contra gli christiani che andauano ad imbarcarsi, & altri per venir
contra il campo *del Gouernatore*, per veder se poteua esser liberato: &
questa era vna gran moltitudine di gente, però la maggior parte
veniua per forza, o per tema che haueano. Come il signor Gouer-
nator fu di tal cosa informato, parlò al Cacique *adirato*, dicendogli che
gli portamenti suoi eran molto tristi, poi che *senza causa*[1] faceua venir
gente contra di noi. Pochi giorni auanti eran venuti al nostro campo
duoi indiani figliuoli del Cusco vecchio, fratelli di Atabalipa, da canto
di padre & non di madre: questi vennero molto ascosamento per
timor di suo fratello. Quando il Gouernatore seppe che erano figliuoli
del Cusco vecchio, fece loro molto honore, perche nel aspetto mo-
strauano esser figliuoli di gran signore. Dormiuano costoro ap- 13 v
presso il Gouernatore: perche non haueano ardimento di dormir in
altra parte, per timor di *Atabalipa*. Vn di questi era natural signore
di quella terra, laquale gli rimaneua dopo la morte di suo fratello. In
questi medesimi giorni vennero nuoue che la gente di guerra era molto
propinqua: & per tal causa noi stauamo molto vigilanti. & vna notte
vennero alcuni indiani fuggendo d'vn luogho che era li vicino, dicendo

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[1] 1545: luy disant qu'il estoit vn faux traistre & desloyal de luy auoir brassé tant d'alarmes, & trahysons sans aucune occasion de mal traictement dont à bon droict il se peust plaindre.

que venian de guerra les auian desbaratado su mayz y que venian a dar en el real de los christianos: y que por esso venian ellos huyendo. Como esto supo el señor gouernador: huuo consejo con sus capitanes: y con los oficiales de su magestad. Y determinaron de matar luego aquel gran cacique Atabalipa: el qual lo merecia: y assi lo sacaron en anocheciendo a la plaça: y le ataron a vn palo: y por mandado del señor gouernador lo quisieron quemar biuo. Mas como Dios lo quiso conuertir: dixo que queria ser christiano. y assi lo ahogaron aquella noche: que otras muchas auia que la gente no dormia ni sossegaua con temor de los indios y de aquel cacique. El gouernador proueyo aquella noche de quien velasse al cacique muerto: y otro dia de mañana lo enterraron en vna yglesia que alli teniamos. y muchas indias se querian enterrar biuas con el. De la muerte deste cacique se alegro toda aquella tierra: y no podian creer que era muerto. Luego fue la nueua a la gente de guerra: y luego se fue cadauno a su tierra, que por fuerça eran venidos alli los mas. ❡ El señor gouernador alço por señor de aquella tierra al hijo mayor del Cuzco viejo con condicion que quedassen el y toda su gente por vassallos del emperador: y el prometio de hazer. Luego vino gran multitud de gente

Xerez *C7v1:*

❡ Agora quiero dezir vna cosa admirable: y es que veynte dias antes que esto acaesciesse ni se supiesse de la hueste que atabaliba auia hecho juntar. estando atabaliba vna noche muy alegre con algunos españoles hablando con ellos: parecio a desora vna señal en el cielo a la parte del Cuzco como cometa de fuego que duro mucha parte de la noche y vista esta señal por Atabaliba dixo que muy presto auia de morir en aquella tierra un gran señor.

Xerez *C7v1:*

Luego todos los señores principales y caciques que presentes se hallaron con mucho acatamiento lo recibieron por señor y le besaron la mano y en el carrillo. y boluiendo las caras al sol, le dieron gracias las manos juntas diziendo que les

che gli indiani veniuano per far guerra, & che haueuan rouinati loro li mahizali, *che sono campi doue nasce il grano del mahiz,* & che veniuano per assaltare il campo de christiani, & che per questo loro veniuano fuggendo. Come questo seppe il signor Gouernatore fece consiglio con gli suoi capitani, & con gli officiali di sua Maesta, & determinorono di far morir subito Atabalipa, ilqual lo meritaua. Menoronlo adunque al far della notte nella strada & legoronlo ad vn palo: & per comandamento del signor Gouernatore lo volsero abbruciar viuo: ma volse Iddio conuertirlo, perche disse che voleua esser christiano: & per questo lo annegorono[1] in quella notte, laqual con molte altre era passata che le nostre genti non haueuan dormito, per timor delli indiani: & di questo Cacique. Il Gouernator prouidde che fusse fatto la guardia al detto Cacique morto, & il giorno seguente da mattina il sepelirono in vna chiesa che haueuano quiui, *doue* molte femine indiane si voleuano sepelir viue con lui. *Venti giorni auanti che morisse Atabalipa, non si sapendo cosa alcuna del essercito che aspettauano, & essendo Atabalipa vna sera molto allegro, & parlando con alcuni spagnuoli, apparse in aere verso la citta del Cusco à modo d'una cometa di fuoco, laquale stette gran parte della notte, & come Atabalipa l'hebbe veduta disse, presto morira vn gran signore di quel paese: & questo fu lui.* De la morte di questo Cacique si allegrò tutto quel paese: & non poteuan creder che fusse morto, subito che la nuoua andò alla gente di guerra, immediate ciascuno tornò a casa sua: perche erano venuti per forza. Il signor Gouernator fece far signor di quella terra il figliuolo maggiore del Cusco vecchio, con conditione che restassino, lui & tutta la sua gente, per vassalli de l'Imperadore, & cosi loro promisero di fare. Subito *che il figliuol del Cusco vecchio fu fatto signore, le genti del paese alzorono le mani al sole, ringratiandolo, che*

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[1] 1556, 1565, 1606: lo fecero strangolare. 1535: lo annegorono. 1545: Si le menerent entre nuyt & iour en la rue, l'attacherent à vn posteau ou ilz luy appareillerent beau feu pour le rostir par le commandement du gouuerneur si dieu n'eust prins pitié de luy le conuertissant à sa sainte foy. Car il dit lors qu'il auoit vouloir de deuenir bon chrestien, dont luy fut la cruaute de la mort moderée, & le feu conuerty en l'eau. Marginal note, 1545: Lamort d'Atabalipa qui fut noyé.

por mandado del cacique a seruir de buena voluntad. Assi mesmo se holgo de la muerte de Atabalipa el capitan Chilicochima: diziendo que por causa del estaua medio quemado: Y que el daria todo el oro de la tierra, que auia mucho mas de lo que Atabalipa auia dado: porque el que auian alçado por señor, era natural señor de aquella tierra: aquel dia truxo quatro cargas de oro y ciertos copones. Antes que Atabalipa muriesse auia mandado traer vn pastor con ouejas de oro, y otras pieças muy ricas. Y esto todo venia para el real. Y aconsejaron al señor gouernador que no lo hiziesse venir luego aquel oro porque aquellos que se venian a Castilla no ouiessen parte. Desto no me despido de auer mi parte, pues lo ayude a ganar. Estas pieças eran muy grandes: otros muchos y yo oymos dezir al cacique: que no hiziessen boluer aquel oro a tras: porque el esperaua mucho mas que le auian de traer mas de dozientos indios: y el gouernador le dixo que ellos auian de yr por alli y lo recogerian: y esto se hazia porque no ouiessen parte los que se yuan a Castilla. Yo digo que vi quedar alla despues de la particion del oro vna grande[1] caxa llena de vasos de oro y otras muchas pieças. Todo esto no se repartio: en lo qual tenian parte los que yuan a Castilla, que se hallaron en aquella batalla ya dicha. ¶ Mas digo que vi pesar y quedar alla del quinto de su magestad, sin lo que lleuo el señor Fernando piçarro, mas de ciento y ochenta mil pesos. Esto es lo que en esta tierra hauemos passado: y otras muchas cosas se me han passado de la memoria. De todo lo bien hecho se de la gloria a Dios que nos dio vertud y esfuerço
7 v para lo obrer: ¶ Se que dixo el cacique que ay otros muchos

auia dado señor natural. Assi fue recebido este señor al estado de Atabaliba: y luego le pusieron vna borla muy rica atada por la cabeça que desciende desde la frente que quasi le tapa los ojos: que entre ellos es corona que trae el que es señor en. el señorio del Cuzco: y assi la traia Atabaliba

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[1] Original: grunde.

gli hauea dato il suo signor naturale, & fu messo in possessione 14 r *dello stato, & messongli vn fiocco molto ricco legato con vna cordella intorno alla testa, ilquale gli veniua tanto su la fronte che gli copriua quasi gliocchi, & questa è la corona che porta quel che è signor del paese del Cusco, & cosi portaua Atabalipa. Ilche poi che fu fatto* venne gran moltitudine di gente per seruirne, & questo per comandamento di questo signor *nuouo.* Similmente si allegrò della morte di Atabalipa, il capitan Chilicuchima, dicendo che per causa sua era stato mezzo abbruciato: & che daria tutto l'oro di quella terra che ne haueua *gran quantita, &* molto piu di quello che Atabalipa hauea dato, perche quello che hauean fatto signore, era natural signore di quella terra: & in quel giorno menorono quattro cariche d'oro, & certe coppe grandi. *Alcuni giorni* auanti che Atabalipa morisse haueua ordinato che fussero portati *vna statua d'*vn pastor con le pecore d'oro, & altri pezzi molto ricchi. & questo tutto veniua per conto *della gente nostra* di campo. Ma il signor gouernatore fu consigliato che non facesse portar allhora quel oro, accioche quelli che si partiuano & tornauano in Castiglia non ne hauessero la lor parte. *Ilche* inteso dal Cacique,[1] *come* io & molti altri vdimo dire, *disse al signor Gouernatore* che non facesse ritornar quello oro indietro, perche ne aspettaua anchora molto maggior pezze, lequali doueuan portar piu di dugiento indiani. *allequali parole di Atabalipa* rispose il Gouernatore, che erano per andar in quel paese & che tutto lo raccoglierebbeno. & tutto questo faceua accioche non si hauesse à partire con quelli che andauano in Castiglia. Io dico che viddi restar vna gran casa piena di vasi d'oro, & altri pezzi dapoi che fu fatta la sopradetta diuisione, liquali vasi si doueuano partire fra noi, che tornauamo in Castiglia, essendoci trouati nella battaglia, *con tante fatiche, con quante* di sopra è stato narrato. Et piu dico che io viddi pesare, & restar li del quinto di sua Maesta,[2] senza quello che portò il signor Hernando Pizarro, piu di cento & ottanta mila pesi. *Questo non voglio restar di dire,* che disse il Cacique

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[1] 1545: i'ay oy dire que quand le noueau Cacique eust entendu son intention, luy dit qu'il ne laissast pour cela à faire venir le pasteur & les brebis d'or.

[2] 1545: Ie ne puis taire que i'ay veu, outre le cinquiesme du seigneur gouuerneur, deduyt tout ce que le capitaine son frere pouoit pretendre de son droict, encores ay ie veu rester tout rabatu, qui faisoit à rabatre, plus de cent quatre vint mille liures d'or ou d'argent.

indios de aquella tierra de Coallo: y que ay vn rio muy grande en el qual ay vna ysla donde ay ciertas casas: y que entre ellas esta vna muy grande toda cubierta de oro, y las pajas hechas de oro: porque los indios nos truxeron vn manojo dellas. y que las vigas y quanto en la casa ay todo es oro: y que tiene el suelo empedrado con granos de oro por fundir: y que tiene dentro de ella mucho oro por fundir. y esto oy dezir al cacique y a sus indios que son de aquella tierra estando presente el gouernador. Dixo mas el cacique que el oro que sacan de aquel rio no lo cogen en bateas: antes lo cogen en vnas acequias que hacen salir de aquel rio que laua la tierra que tienen cauada: y assi mesmo quitan el agua de aquella acequia como esta lauada, y cogen el oro y los granos que hallan que son muchos: y esto yo lo oy muchas vezes: porque a todos los indios de la tierra de Collao que lo preguntauan dezian que esto era assi verdad. Y de

XEREZ *C7v2:*

Y en este camino padescieron desde la ciudad del Cuzco hasta el puerto, que son quasi dozientas leguas, mucha hambre y sed y trabajo y falta de quien les truxesse su hazienda: y assi embarcando se vinieron a Panama: y desde alli al nombre de Dios a donde se embarcaron: y nuestro señor los truxo hasta Seuilla a donde hasta agora son venidas quatro naos: las quales truxeron la siguiente quantidad de oro y plata. . . .

⸿ *Año de mil y quinientos y treynta y quatro a nueue de enero llego al rio de Seuilla la segunda nao nombrada santa Maria del campo, en la qual vino el capitan Hernando piçarro hermano de Francisco piçarro gouernador y capitan general de la nueua Castilla. En esta nao vinieron para su magestad ciento y cincuenta y tres mil pesos de oro y cinco mil y quarenta y ocho marcos de plata. Mas truxo para passageros y personas particulares trezientos y diez mil pesos de oro y treze mil y quinientos marcos de plata sin lo de su magestad. lo sobredicho vino en barras y planchas y pedaços de oro y plata cerrado en caxas grandes.*

⸿ *Allende de la sobredicha quantidad truxo esta nao para su magestad treynta y ocho vasijas de oro y quarenta y ocho de plata . . . Item en esta nao truxeron de passageros veynte y quatro cantaros de plata y quatro de oro.*

⸿ *Este thesoro fue descargado en el muelle y lleuado a la casa de la contratacion las vasijas a cargas y lo restante en veynte y siete caxas: que vn par de bueyes lleuauan dos caxas en vna carreta.*

OVIEDO. *1526. Fol. 3r/3v:*

La nauegacion desde España: que comunmente se haze para las indias, es desde Seuilla, donde .V.M. tiene su casa real de contratacion, para aquellas

Atabalipa, che era vn paese detto Collao, doue è vn fiume molto grande, nelquale è vna isola, doue sono certe case, tra lequali ne era vna molto grande, tutta coperta d'oro, fatto in modo di paglia: della quale alcuni indiani *venuti da quella isola* ne portorono vna 14 v
brancata, gli traui, & tutto il resto ch'era in casa, tutto era *coperto di piastre* d'oro, & che vi era il pauimento fatto con grani d'oro, cosi come lo trouauano nelle minere. & questo vdi dire al Cacique, & alli suoi indiani che erano di quella terra *venuti a vederlo*, presente il *signor* Gouernatore. Disse di piu il Cacique, che l'oro che si caua di quel fiume, non lo ricogliono con bateas, *che sono a modo di vno bacil da barbiere, con gli manichi doue lauano l'oro nell'acqua*, anzi *fanno in questo modo, che* mettono la terra cauata de la minera, in *vn luogho a modo d'*una fossa *appresso l'acqua*, & *con vna ruota* cauano l'acqua del fiume, *& la fanno andar in quella fossa*, & cosi lauano la terra: laqual lauata leuano via l'acqua, & ricogliono i grani de l'oro che sono molti, *& grandi*, & questo io l'ho vdito dire molte volte, perche tutti quelli indiani della terra di Collao, liquali *io* domandauo: diceuano cosi esser la verita. *Il Gouernator Francesco Pizarro dette à noi che veniuamo in Castiglia tutto l'oro & l'argento che era della parte della Maesta*[1] *del Imperadore. Et da la prouincia del Cusco ouer del Peru, donde partimmo per andare ad imbarcarci alla marina, caminammo dugiento leghe per terra: doue arriuati montammo in naue, & nauigammo per il mare del Sur, fino al porto della citta di Panama in quindici giorni, doue dismontati fummo accettati con grandissima allegrezza, & ammiratione di tutti, per la gran quantita de l'oro che viddero. Il Signor Gouernatore Pedrarias ci prouidde di tutte le cose necessarie, per portar detto oro & argento, quelle ottanta miglia per terra, fino alla citta del Nome di Dio, che è sopra l'altro mar del Nort, che vien in Spagna, come nel principio di questo libro è detto. Giunti che fummo alla citta del Nome di Dio, & imbarcati venimmo a l'isola spagnuola, & arriuammo alla citta di san Domenico, che è nella parte de l'isola che guarda verso mezzo di: & questo viaggio facemmo in otto giorni, doue tolti li rinfrescamenti necessarii per venir alla volta di Spagna, voltammo le prore verso leuante,*

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[1] 1545: le gouuerneur liura la part imperialle de la conqueste d'or.

todo esto yo hago fe y testimonio[1] como testigo de vista que a todas estas cosas me halle presente con el muy magnifico y esforçado cauallero Francisco piçarro Gouernador Y Capitan general en aquella tierra por su magestad a quien Dios siempre prospere. Amen. ✠

8 v ❡ Esta obra fue impressa en la muy noble y muy leal ciudad de Seuilla, en casa de Bartolome perez. en el mes de Abril. ✠ Año de mil y quinientos y treynta y quatro.

partes: y sus oficiales delos quales toman licencia los capitanes y maestres delas Naos que aquel viaje hazen: y se enbarcan en sant Lucar de barrameda donde el rio de Guadalqueuir entra enel mar Oceano: y de alli siguen su derrota para las yslas de Canaria, y comunmente tocan en vna de dos de aquellas siete que son: y es, en gran Canaria, o enla Gomera, y alli los nauios toman refresco de agua y leña y quesos y carnes frescas y otras cosas, las que les pareçe que deuen añadir sobre el principal bastimento que ya desde españa lleuan. A estas yslas desde España tardan comunmente ocho dias poco mas, o menos: y llegados alli, an andado dozientas y cinquenta leguas . . . y de alli hasta llegar ala cibdad de santo Domingo que es en la ysla Española . . . Assi que desde españa hasta alli ay: mil y trezientas leguas: pero como se nauegan, bien se andan mil y quinientas, y mas. Tardasse enel viaje comunmente, treynta y cinco, o quarenta dias . . . La buelta desde aquellas partes a estas, suele ser de algo mas tiempo, assi como hasta cinquenta dias, pocos mas o menos . . . Es la nauegacion muy segura y muy vsada hasta la dicha ysla: y desde ella a tierra firme atrauiessan las naos en cinco y seys, y siete dias, y mas, segun ala parte donde van guiadas: proque la dicha tierra firme es muy grande . . .

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[1] Original: testimoni(?)

tenendole sempre tra greco[1] *& leuante, & nauigammo da .52. giorni, & facemmo .1350. leghe, fino alli liti di Spagna doue è san Luca di Barameda, in sul fiume di Guadachibir, secondo la ragione che faceuano gli piloti nostri, anchor che io penso che fussero molte piu: & hauemmo bonissimo tempo, & arriuammo alla citta di Sibilia, doue tutte le* 15 r *naui sogliono discaricare le robe che portano dalle indie. In questo viaggio da l'isola spagnuola non toccammo se non le isole delle Canarie; anchor che alchuni tocchino le isole delli Azori, & come fummo allontanati da terra cinquecento in seicento miglia, trouammo il mar basso, ne dubitammo piu di fortuna, perche gli venti non fanno fortuna se non appresso terra, cioè appresso l'isola spagnuola, ouer appresso gli liti di Spagna, doue il mar è profondissimo, & nauigammo gran parte con l'instrumento del quadrante, con il sole, fin che appressandoci al nostro habitabile, cominciammo à reggerci con la tramontana.*[2] *Questa nauigatione è molto sicura, per infiniti piloti che sono pratichi di quella. Arriuammo in Sibilia alli quindici giorni di Genaio .1534. doue furono discaricati tutti li ori & argenti, con grandissima ammiratione di tutta la citta, & di infiniti mercatanti Fiorentini, Genouesi, & Venetiani, liquali tutti corsono à veder tal cosa, & dipoi hauendone scritto per il mondo: io non ne diro altro, saluo che tutti noi con la parte delli nostri ori partimmo, & andammo à casa nostra, doue fummo riceuuti con quella allegrezza che ogn'un si puo pensare.*

FINE.

In Vinegia, Del mese d'Ottobre.

M D XXXIIII.

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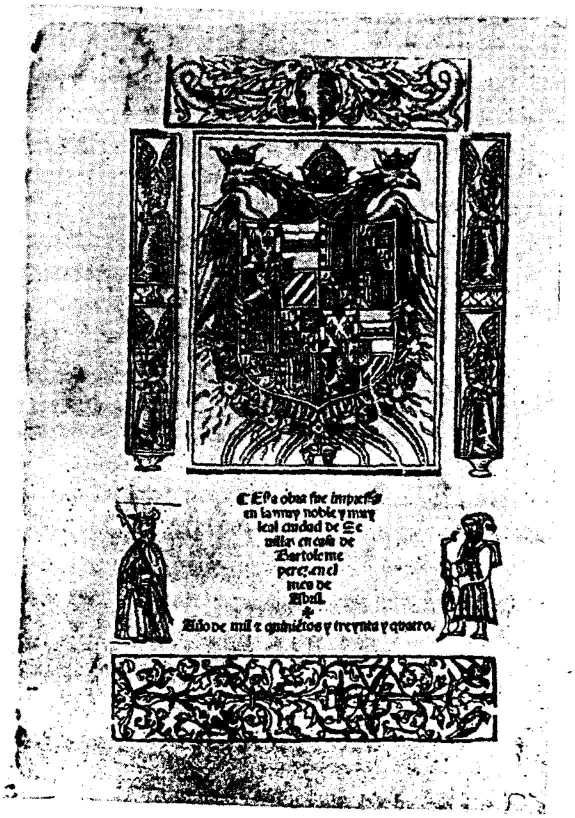
[1] Marginal note, 1545: Vent grec c'est Oest nordest.

[2] 1545: ou nous choisismes lourse pour guyde. Marginal note, 1545: Quadrent autrement dit Busolle. L'ourse autrement ditte Tramontane.



¶ Esta obra fue impressa
en la muy noble y muy
leal ciudad de Se
villa: en casa de
Bartoleme
perez: en el
mes de
Abril.

Año de mil e quinientos y treynta y quatro.

FIG. 1. Item (B). Colophon-page. About ⅓ actual size.
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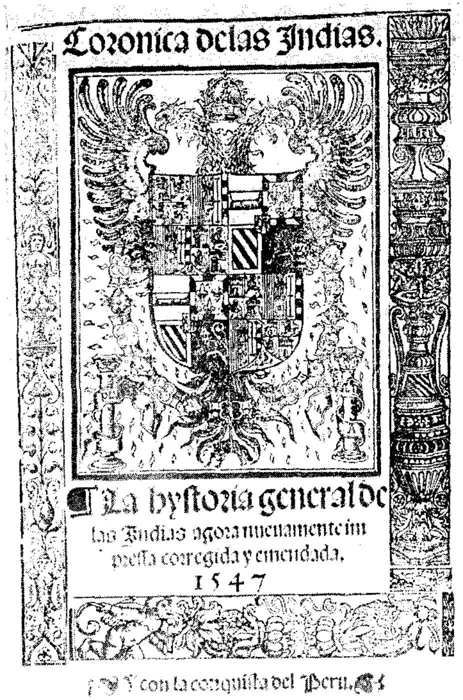
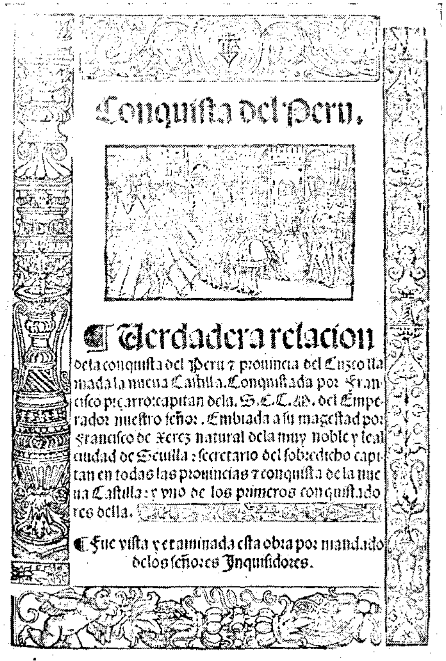


Coronica delas Indias.

La hyſtoria general de las Indias agora nueuamente impreſſa corregida y emendada.
1547

Y con la conquiſta del Peru.

FIG. 14. Item (N). First title-page. About ⅓ actual size.
Harvard Library copy.



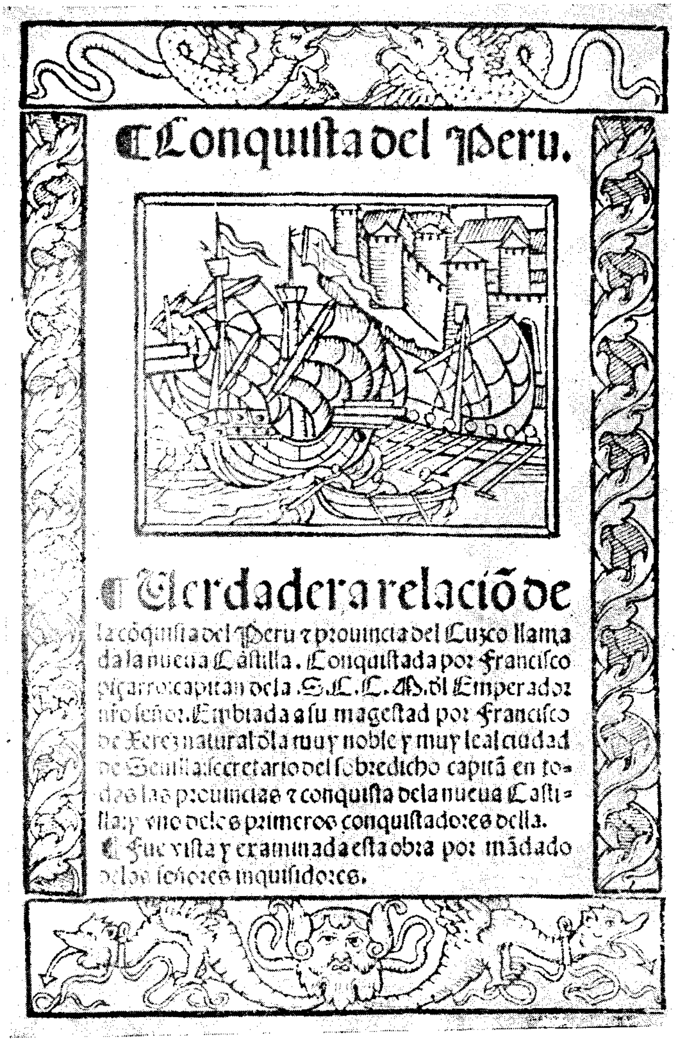
Conquiſta del Peru.

Verdadera relacion

dela conquiſta del Peru ⁊ prouincia del Cuzco llamada la nueua Caſtilla. Conquiſtada por Franciſco piçarro: capitan dela. S.C.C.M. del Emperador nueſtro ſeñor. Embiada a ſu mageſtad por Franciſco de Xerez natural dela muy noble y leal ciudad de Seuilla: ſecretario del ſobredicho capitan en todas las prouincias ⁊ conquiſta dela nueua Caſtilla: y vno de los primeros conquiſtadores della.

Fue viſta y examinada eſta obra por mandado delos ſeñores Inquiſidores.

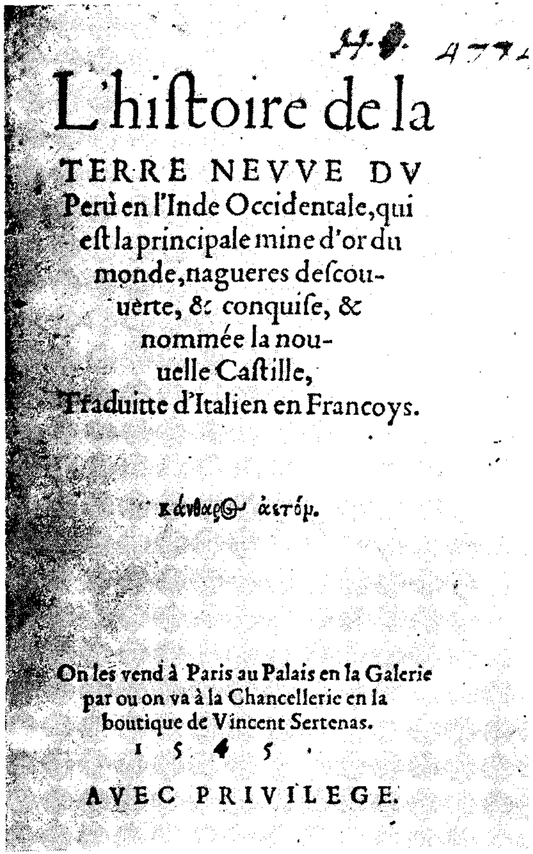
FIG. 15. Item (N). Second title-page [same as (M)]. About ⅓ actual size.
Harvard Library copy.



¶ Conquiſta del Peru.

¶ Verdadera relaciō de
la cōquiſta del Peru ⁊ prouincia del Cuzco llama
da la nueua Caſtilla. Conquiſtada por Franciſco
piçarro: capitan dela .S.C.C.M. dl Emperador
nr̃o ſeñor. Embiada a ſu mageſtad por Franciſco
de Xerez natural dla muy noble y muy leal ciudad
de Seuilla: ſecretario del ſobredicho capitā en to-
das las prouincias ⁊ conquiſta dela nueua Caſti-
lla: y vno delos primeros conquiſtadores della.
¶ Fue viſta y examinada eſta obra por mādado
delos ſeñores inquiſidores.

FIG. 13. Item (L). Title-page. About ¾ actual size. Former Huth copy, now in the Wm. L. Clements Library.



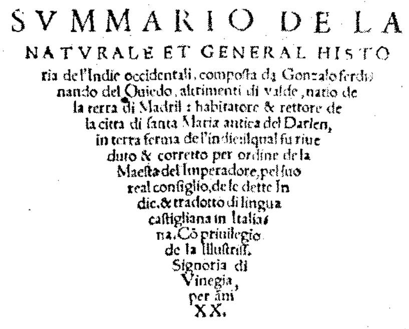
H. 477

L'hiſtoire de la
TERRE NEVVE DV
Perù en l'Inde Occidentale, qui
eſt la principale mine d'or du
monde, nagueres deſcou-
uerte, & conquiſe, &
nommée la nou-
uelle Caſtille,
Traduitte d'Italien en Francoys.

κάνθαρος ἀστόρ.

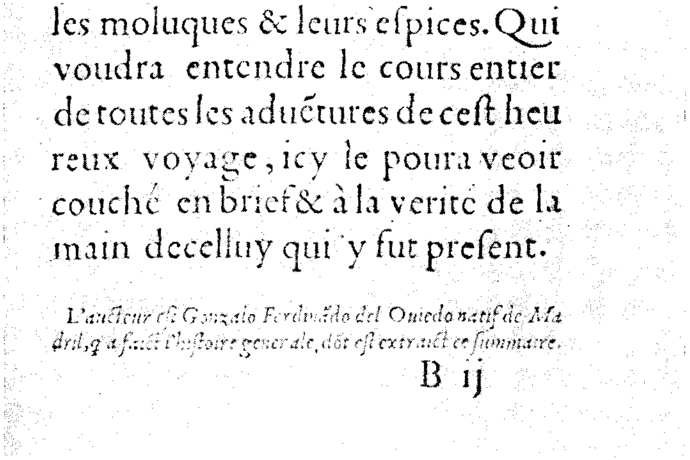
On les vend à Paris au Palais en la Galerie
par ou on va à la Chancellerie en la
boutique de Vincent Sertenas.
1 5 4 5 .
AVEC PRIVILEGE.

FIG. 10. Item (K). Title-page. About ¾ actual size. Ternaux-Compans copy of the N. Y. P. L.



SVMMARIO DE LA
NATVRALE ET GENERAL HISTO
ria de l'Indie occidentali, compoſta da Gonzalo ferdi-
nando del Ouiedo, altrimenti di valde, natio de
la terra di Madril: habitatore & rettore de
la citta di ſanta Maria antica del Darien,
in terra ferma de l'indie: ilqual fu riue
duto & corretto per ordine de la
Maeſta del Imperadore, pel ſuo
real conſiglio, de le dette In
die. & tradotto di lingua
caſtigliana in Italia-
na. Cō priuilegio
de la Illuſtriſſ.
Signoria di
Vinegia,
per āni
XX.

FIG. 11. Item (E). Second title. About ½ actual size. Lenox copy of the N. Y. P. L.

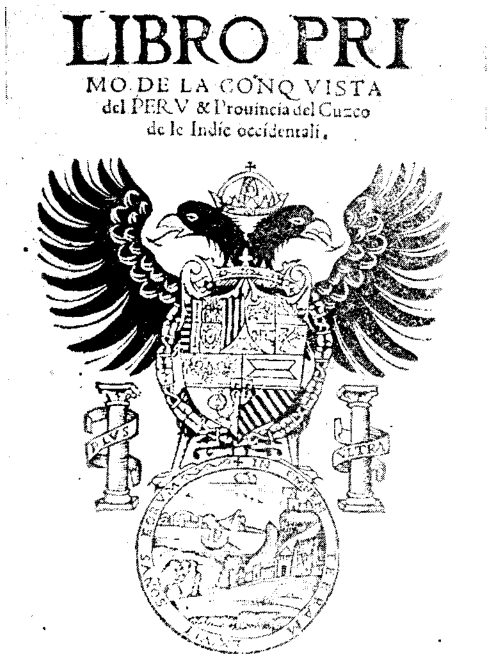


les moluques & leurs eſpices. Qui
voudra entendre le cours entier
de toutes les aduẽtures de ceſt heu
reux voyage, icy le poura veoir
couché en brief & à la verité de la
main de celluy qui y fut preſent.

*L'aucteur eſt Gonzalo Ferdinãdo del Ouiedo natif de Ma
dril, q̃ a faict l'hiſtoire generale, dõt eſt extraict ce ſommaire.*

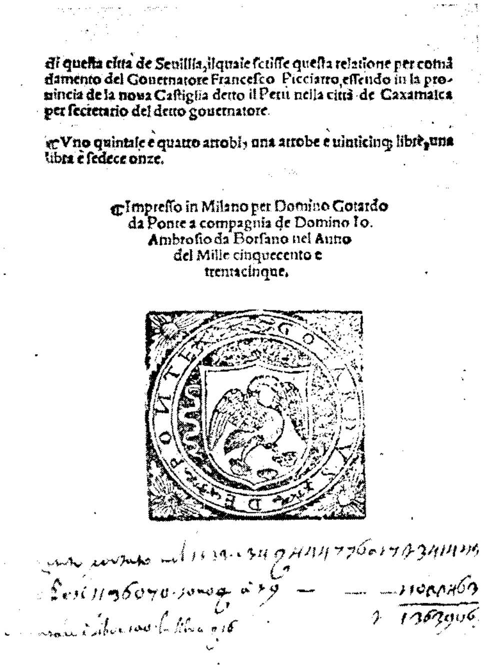
B ij

FIG. 12. Item (K). Authorship note. About actual size. Maitland copy of the N. Y. P. L.



LIBRO PRI
MO DE LA CONQ VISTA
del PERV & Prouincia del Cuzco
de le Indie occidentali.

FIG. 8. Item (H). Title-page. About ½ actual size. New York Public Library copy.



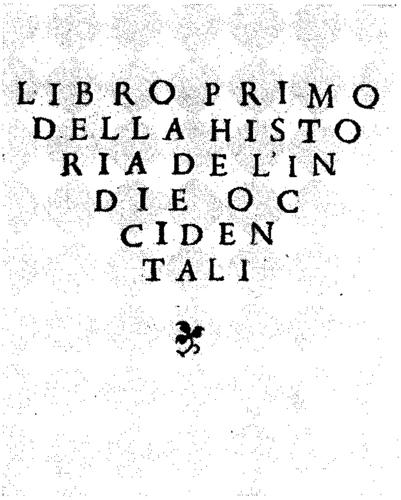
di queſta citta de Seuillia, ilquale ſcriſſe queſta relatione per comã damento del Gouernatore Franceſco Picciarro, eſſendo in la prouincia de la noua Caſtiglia detto il Peru nella città de Caxamalca per ſecretario del detto gouernatore.

¶Vno quintale è quatro arrobi, una arrobe è uinticinq; libre, una libra è ſedece onze.

¶Impreſſo in Milano per Domino Gotardo
da Ponte a compagnia de Domino Io.
Ambroſio da Borſano nel Anno
del Mille cinquecento e
trentacinque.

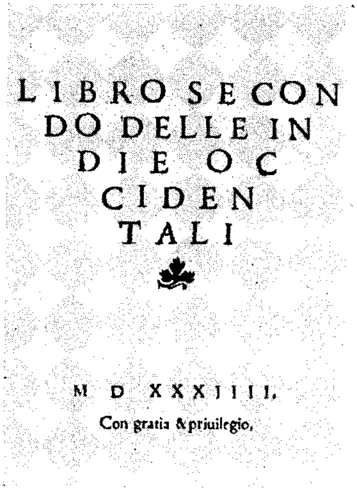
[illegible]
[illegible]
[illegible] 1363906

FIG. 9. Item (H). Colophon-page. About ½ actual size. New York Public Library copy.



LIBRO PRIMO
DELLA HISTO
RIA DE L'IN
DIE OC
CIDEN
TALI

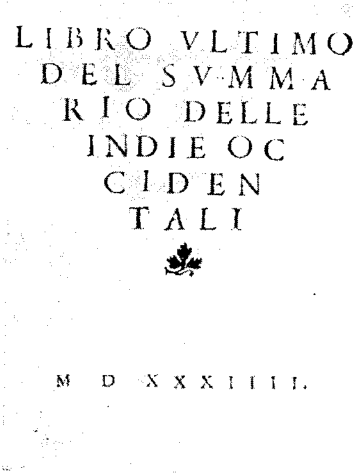
FIG. 4. Item (D). Title-page. About ½ actual size.
Lenox copy of the N. Y. P. L.



LIBRO SECON
DO DELLE IN
DIE OC
CIDEN
TALI

M D XXXIIII.
Con gratia & priuilegio.

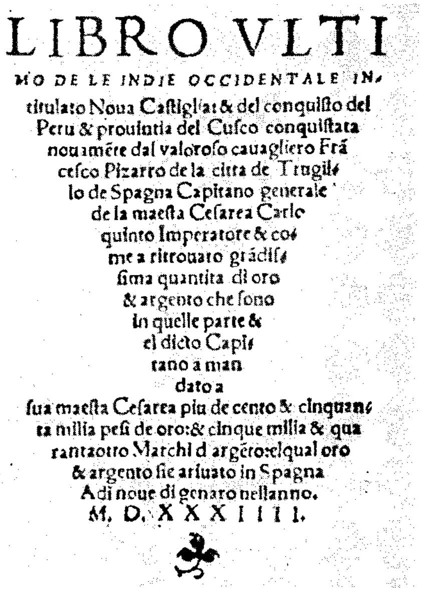
FIG. 5. Item (E). Title-page. About ½ actual size.
Lenox copy of the N. Y. P. L.



LIBRO VLTIMO
DEL SVMMA
RIO DELLE
INDIE OC
CIDEN
TALI

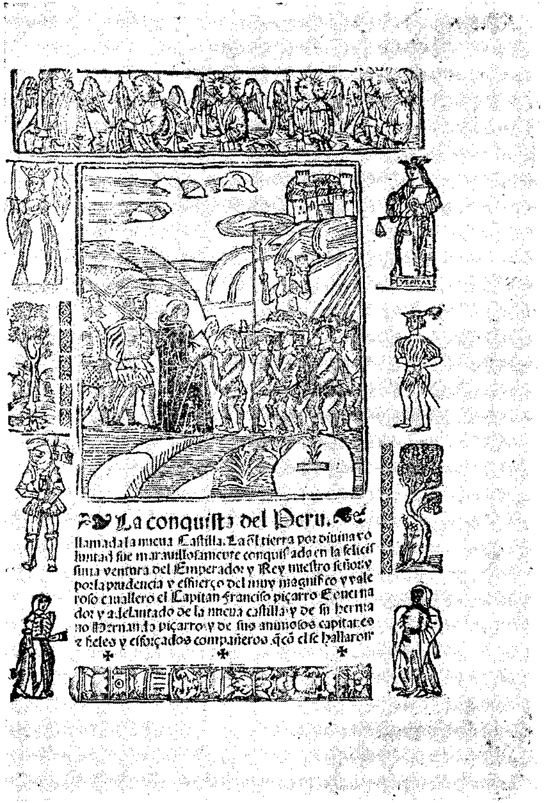
M D XXXIIII.

FIG. 6. Item (F). Title-page. About ½ actual size.
Lenox copy of the N. Y. P. L.



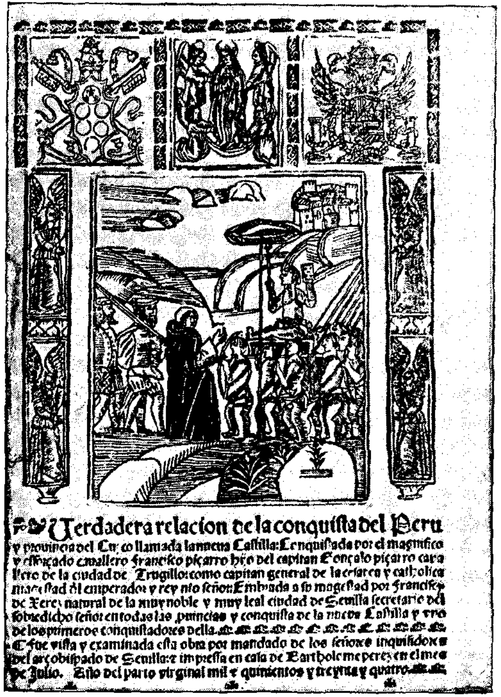
LIBRO VLTI
MO DE LE INDIE OCCIDENTALE IN-
titulato Noua Caſtiglia: & del conquiſto del
Peru & prouintia del Cuſco conquiſtata
nouamēte dal valoroſo cauagliero Frā
ceſco Pizarro de la citta de Trugil-
lo de Spagna Capitano generale
de la maeſta Ceſarea Carlo
quinto Imperatore & co-
me a ritrouato grādiſ-
ſima quantita di oro
& argento che ſono
in quelle parte &
el dicto Capi-
tano a man
dato a
ſua maeſta Ceſarea piu de cento & cinquan-
ta millia peſi de oro: & cinque millia & qua
rantaotto Marchi d argēto: elqual oro
& argento ſie ariuato in Spagna
Adi noue di genaro nellanno.
M. D. XXXIIII.

FIG. 7. Item (I). Title-page. About ⅔ actual size.
New York Public Library copy.



La conquiſta del Peru.
llamada la nueua Caſtilla. La q̃l tierra por diuina vo
luntad fue marauilloſamente conquiſtada en la felici
ſsima ventura del Emperador y Rey nueſtro ſeñor: y
por la prudencia y esfuerço del muy magnifico y vale
roſo cauallero el Capitan Franciſco piçarro Gouerna
dor y adelantado de la nueua caſtilla: y de ſu herma
no Hernando piçarro: y de ſus animoſos capitanes
e fieles y esforçados compañeros q̃ cõ el ſe hallaron

FIG. 2. Item (B). Title-page. About ⅓ actual size. New York Public Library copy.



Verdadera relacion de la conquiſta del Peru
y prouincia del Cuzco llamada la nueua Caſtilla: Conquiſtada por el magnifico
y esforçado cauallero Franciſco piçarro hijo del capitan Gonçalo piçarro caua
llero de la ciudad de Trugillo: como capitan general de la ceſarea y catholica
mageſtad del emperador y rey nro ſeñor: Embiada a ſu mageſtad por Franciſco
de Xerez natural de la muy noble y muy leal ciudad de Seuilla ſecretario del
ſobredicho ſeñor en todas las prouincias y conquiſta de la nueua Caſtilla y uno
de los primeros conquiſtadores della.
¶ Fue viſta y examinada eſta obra por mandado de los ſeñores inquiſidores
del arçobiſpado de Seuilla: e impreſſa en caſa de Bartholome perez en el mes
de Julio. Año del parto virginal mil e quinientos y treynta y quatro.

FIG. 3. Item (C). Title-page. About ⅓ actual size. New York Public Library copy.

Proceedings of the American Academy of Arts and Sciences.

VOL. 64. NO. 9.—AUGUST, 1930.

THE JOULE-THOMSON EFFECT IN AIR.

SECOND PAPER.

BY J. R. ROEBUCK.

THE JOULE-THOMSON EFFECT IN AIR.

SECOND PAPER.

By J. R. Roebuck.

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1. Introduction.

In an earlier paper[1] I have described the experimental set-up and detailed the results of the measurements on air at temperatures

---

A number of errors and misprints in the first Article[1] should be corrected as follows:

pp. 563–564, Tables I, Flow L/min. to Flow L/sec.
568–573, Tables II–IX, Flow L/min. to Flow L/sec.
568, second paragraph, line 5, minute to second
585, Table XI, Column 5, row 6, 0.0800 to 0.0700
589, Table XV, Column 2, row 3, 272.12 to 272.42
594, Fig. 15, On lowest Curve, 200° C to 250° C.

above that of the room. In the present article the data are extended to cover the available range below room temperatures.

The apparatus and procedure are essentially those described in the earlier paper, so that here it will be necessary only to describe modifications of apparatus and procedure required by the different conditions or suggested by more extended experience.

The steady growth in complexity of the apparatus over the years while this problem has been studied finally made it virtually impossible —or at least impracticable—for one worker to run the outfit and collect the data; consequently J. H. Webb joined me in the work and all of the data here presented, as well as some of the calculations, are the result of our joint effort. Upon J. H. Webb's departure, Harold Osterberg joined me and some of the calculations toward the end of this article are his work.

2. THERMOSTAT BATH ARRANGEMENTS.

For temperatures running down to −150° C. it is necessary to use a variety of bath liquids, going to the more expensive materials only as necessity arises. Good kerosene serves for temperatures to perhaps −50° C., but is apt to become viscous and is better changed to gasoline after −25° C. The highest grade of gasoline could be used to about −80° C. Petrolic ether (benzin petroleum) could be used to −120° C. while below this isopentane[2] served to −150° C. The cost increases in this order, but in no case was serious for the 4 gallons necessary to fill the bath. Several times liquids were used when their increased viscosity or partial solidification made them unsuitable. The performance of the apparatus and the vagaries of the data showed it unmistakably.

3. BATH REFRIGERATION.

For the runs at 0° and −25° only, the coil in the lower part of the bath (See First Paper, Fig. 1) was rotated to new openings, connected outside to the carbon dioxide refrigeration system, and the apparatus was cooled by its normal use. The compressed condensed gas was brought to the expansion coil through a pipe enclosed in the larger pipe carrying the expanded evaporated gas back to the compressor.

For bath temperatures from −50 to −150° C., the cooling was done by air exactly as in an air liquefier. The general flow diagram for the whole set-up is given in Fig. 1. The air compressed to 215 atm. from either or both compressors (1) and (2) passes through the trap

(3) for the separation of the liquid water, and through the drier (4) filled with stick sodium hydrate, which also serves to remove any carbon dioxide. Here (5) the air flow divides, part being used for cooling and part for passage through the plug. The portion to be used for cooling passes through the tubing of the short exchanger (6), the carbon dioxide boiler (7), and the long exchanger (8), expands to about one atmosphere at the valve (9) into the coil of tubing (10) which is welded to the outside of the steel cylinder forming the thermostat tank. It passes back from here through the exchangers (8) and (6) to the intake of the compressors.

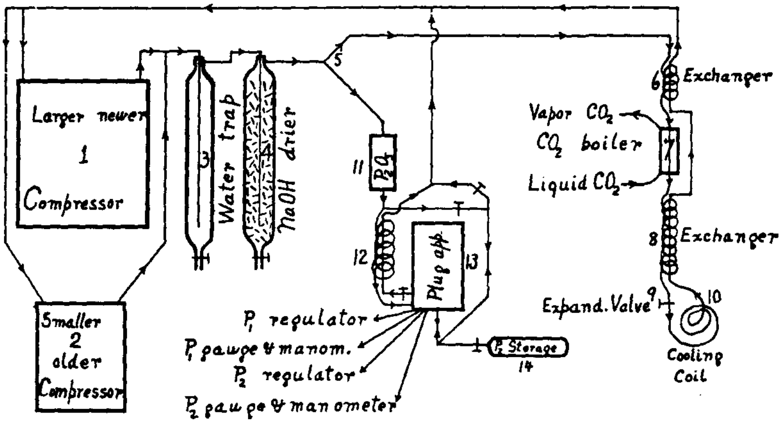
Larger newer
1
Compressor
Smaller
2
older
Compressor
3
Water trap
4
NaOH drier
5
11
P_2O_5
12
Plug app.
13
P_1 regulator
P_1 gauge & manom.
P_2 regulator
P_2 gauge & manometer
P_2 Storage
14
Vapor CO_2
CO_2 boiler
Liquid CO_2
7
6 Exchanger
8 Exchanger
Expand. Valve 9
10
Cooling Coil

FIGURE 1. Flow diagram.

These exchanger coils are new and were constructed as follows— The coil of (8) was made of four pieces of copper tubing each 50 ft. long, $\frac{3}{16}''$ o.d., $\frac{1}{8}''$ i.d., wound in parallel to form flat "pancake" coils so that each pipe always progressed axially in one direction. The method of doing the winding is new and will be described elsewhere. The coil was carried on a $\frac{5}{8}''$ diam. spindle and slipped into a 3″ i.d. brass tube. This brass case was later changed to red fiber with metal ends and the increased speed and range of cooling was very noticeable and valuable.

The smaller coil (6) was made of one piece of copper tubing 40 ft. long, $\frac{1}{4}''$ o.d., $\frac{3}{16}''$ i.d., wound like coil (8) in flat "pancakes." The joints required in the tubing were all made by cutting long male and female cones on the tube ends and fastening them together with a minimum of silver solder. Such joints do not modify either inside or outside diameter of the tube, and they bend on the form almost as readily as the rest of the tube. Failure of the silver solder to make a tight joint is very unusual.

The rate of cooling so obtainable varied from 1.4° C. per minute at room temperature to 0.4° C. per minute when the bath was at −150° C. The total time required to cool down to the working temperature was as a maximum about 3 hours. The air coming from the caustic soda drier still carries a trifle of moisture. From −10° to −70° C. this kept clogging the expansion valve, so requiring much attention, but at lower temperatures this ceased, probably due to the deposition of the moisture on the walls of the tubing, whereas at higher temperatures some of it may have formed snow.

4. PLUG AIR SUPPLY.

The part at (5) Fig. 1 of the compressed air destined for passage through the plug passes first through four or five inches depth of phosphorus pentoxide powder contained in a steel (11) tube 3½″ o.d. and 3″ i.d. This at times packed down so that it took several atmospheres to force air through, but the pressure drop was of negligible moment unless the oxide powder had been deliberately packed in filling. From here it passes to the old exchanger (12) and into the plug apparatus (13). It returns over the outside of the pipes of (12) and enters the return to the compressors' intake.

5. THERMOMETERS.

As indicating instruments a mercury thermometer of range 0° to −28° scaled in $\frac{1}{10}$°, and a pentane thermometer of range 0° to −200° C. scaled in 1°, served somewhat to follow the bath temperature. The control mechanism could also be relied on both for actual temperature and for variations. The ultimate reference however was always the inlet thermometer.

The same pair of platinum resistance thermometers and the same auxiliary apparatus were used throughout this work as for the latter part of the work reported in the first paper.[1] Since the Callendar formula cannot be used below about −40° C. the general method described by Van Dusen,[3] by Loomis and Walters,[4] and by Henning[5] was used. The oxygen boiling temperature was chosen as the required extra point having the value −183° C. at 76 cm. Hg given by Van Dusen.

The oxygen hypsometer arrangement is shown in diagram Fig. 2. The oxygen was made by heating pure potassium permanganate

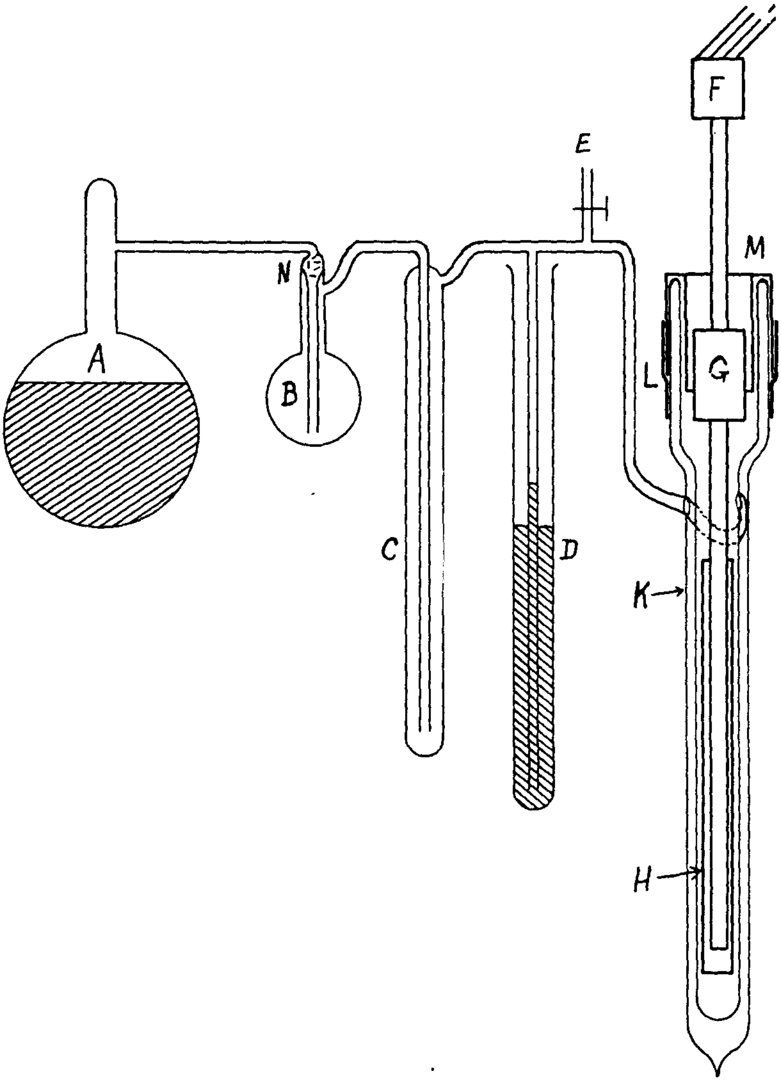

Figure 2. Oxygen boiling point apparatus.

in a large pyrex glass flask A. A certain amount of dust was carried over which was caught almost completely by an asbestos plug, N. The water carried over was partly condensed in the first trap, B, while the residue was largely condensed by the ice salt bath, surrounding C. The final residue was not sufficient to clog the tube where it first became very cold. The apparatus was thoroughly evacuated through E before the permanganate was heated.

In their normal use a heavy metal head, G, on the thermometer is used for fastening it in the apparatus, and hence is held at a temperature usually not far from the temperature being measured. It therefore seems best to cool this head down to the oxygen boiling temperature. The final form of hypsometer used is that shown. The pyrex glass parts are shown by thinner and the metal by heavier lines. The oxygen passes across the vacuum space in K through the coiled glass tube and is condensed by liquid air in the re-entrant metal cup, M, whose upper edge extends over and down the outside of the vacuum vessel where it is made tight by a rubber sleeve, L. The safety tube thrust into the mercury well, D, allowed the use of pressures considerably over one atmosphere during this condensation which proceeded rapidly and easily without overheating the pyrex flask. The liquified oxygen flowed down in contact with the case about the coil of the thermometer. A cylinder of thin aluminum, H, which fitted close to the glass served as a radiation shield. The vacuum tube was not silvered.

When sufficient oxygen had been collected, the liquid air in the re-entrant metal cup was replaced by liquid oxygen made from ordinary commercial oxygen, and the mercury lowered in the safety tube until the system was open to the air. Under these circumstances the liquid oxygen boiled away too rapidly to give confidence in the thermometer reading. To control this the vacuum vessel was immersed in liquid air and the oxygen boiled as slowly as desired by a small heating coil in the bottom of the tube (not shown). With everything thus under control the settings became as steady as could be desired and could be satisfactorily duplicated.

The constants for the thermometers are as follows:—

	δ	β
Therm. X	1.50	0.111
Therm. Y	1.49	0.127

where

$$t = Pt + \delta\left(\frac{t}{100} - 1\right)\frac{t}{100} + \beta\left(\frac{t}{100} - 1\right)\left(\frac{t}{100}\right)^3$$

The data so obtained was used to plot a curve of corrections $(t - Pt)$ against Pt, for each thermometer which was used to make the correction direct from bridge reading to final corrected reading.

In this low temperature work it was difficult to check the difference in resistance of the thermometers at each working temperature. It is less here than at the higher temperatures since the difference falls steadily with the temperature, amounting to only 0.4° C. at −150° C. and also the observed ΔT is usually large. This difference when measured always agreed with the calculated value over the whole range of temperature to well within the limit required by the other errors. This experimental comparison was made at only a few points in the low temperature range.

6. COMPRESSOR.

The two-stage water-lubricated compressor used throughout the earlier work[1] was supplemented here by a three-stage water-lubricated compressor of 60 cu. ft./min. of free air actual capacity, built by the Nordberg Manufacturing Co., Milwaukee. During the preliminary cooling down of the bath both compressors were often used, see Fig. 1. Most of the readings were made with air handled by the larger machine since, on account of the lower temperature, the volumes to be handled in the plug were not so large and the mass flow could therefore be increased materially before kinetic energy effects became appreciable. These larger flows reduce the errors due to heat leakage which were larger in this range on account of the generally larger temperature drops measured. The large compressor was however not so steady in its delivery as the other had become and required a great deal of mechanical attention, particularly to the valves. The replacement of the castor oil by water on the piston rod of the small machine finally abolished the use of oil of any kind in the compressed air system, leaving only water vapor as the main impurity.

7. PRESSURE REGULATION—BAROSTATS.

The high pressure was controlled by the same barostat as used in the latter part of the earlier work. Its steady preformance is of dominant importance in determining the consistency of the data obtained. The single door-spring attached to the rotating piston load was used for all this work. An extended discussion of this regulator will be found in the earlier paper[1] page 549.

The most continual and persistent difficulty found in this work was the slow shift of the pressure (P_2) inside the plug. This was attributed to clogging or unclogging of the plug by condensible material carried by the compressed air, and led to extreme measures to purify the air. The air from the sodium hydrate purifiers, see Fig. 1, was passed through phosphorus pentoxide powder held in a steel tube requiring 0.5–7 atmospheres to force it through. This improved the situation but did not cure it, so it was inferred that substances other than water vapor caused the trouble. The air approaching the plug bath was next passed through a long regenerator built after the Linde model of a casing steel tube and five internal copper tubes. The end where the air turned back on itself was immersed in liquid air, so that as determined by thermocouples along the tube, the flowing air actually approached liquid air temperature. This should effectively condense out any volatile material. While it again improved the situation, it still left P_2 varying too much for satisfactory data. Filtering the air while at this low temperature through cotton to take out snow made no observable difference. This, combined with the failure of many other less extreme measures, made the situation look almost hopeless after some two years of effort. But now the drift was small, usually, so it was decided to try keeping P_2 steady by direct regulation in the hope that the clogging was small enough to allow of satisfactory data.

For the control of P_2 a second rotating piston (see Fig. 4 of earlier paper)[1] was set up and used to operate a valve just as for P_1. A number of arrangements were tried and the most satisfactory was to make this control valve the one in the base of the apparatus through which the air escaped from the plug cavity. A second valve in the base in series with the controlled one, allowed of adjusting the division of pressure drop, so that any desired fraction could be left across the controlled valve. The fraction used was made small enough so that the tendency to hunt was kept within manageable dimensions. A wooden cylinder about four inches in diameter was used on the valve stem to reduce its angular motion as compared with the sliding contact motion, and the motor speed was reduced 96:1 by a worm gear and 4:1 by pulleys. By control of the voltage applied to the 20 volt D.C. motor the overshooting was readily controlled and it was found best to set it so that the motor was in continual motion, and the valve oscillating through a very small angle on each side of the steady setting.

The volume capacity of the plug and passages is small, so an ordinary carbon dioxide storage cylinder, 25 lb. size (see 14 of Fig. 1) was connected to it, and provided with filling and emptying connections direct to the high and low pressure lines in order to economize on the time required for shifting the working pressure.

All this, together with the spring on the rotating cylinder, made the control of this pressure exceed expectations. The situation is much simpler than with P_1, since P_2 is not subject to any erratic rapid variation. The tendency to hunt was under entire control. At a shift in the working pressure, the new pressure became steady immediately and remained so with very little attention. The piston shifts vertically while compensating valve temperature adjustments and possibly some plug clogging, but this lasts only a short time after each shift.

The effect on the data was apparent from the first. The difference of temperature reading settled down immediately to its final value; that is, generally within 5 minutes after setting at a new pressure difference, the temperature difference was steady and would keep the same value to 0.01° for as long as it was followed (30 minutes in one case).

It appears from these observations that the flow varied but very little, particularly at the lowest bath temperatures. The observed drift of the uncontrolled P_2 must therefore be sought elsewhere than from impurities, as for instance in the temperature shift of the valve stem and parts about the valve.

8. General Theory. Thermodynamics.

The porous plug (Joule-Thomson) and the free (Joule or unresisted) expansion experiments belong to that large class of problems in the consideration of which the forms of energy entering the discussion may be restricted to two, heat and work; and the transfers of work may be restricted to those accomplished by a uniform hydrostatic pressure. In such cases it is generally observed that there are only two free variables. On the basis of the conservation of energy, one may write

$$du = dq - pdv$$

where u is the intrinsic energy and q the heat added. Also

$$dq = CdT + h'dp$$

which is the definition of C* and h'. Whence

$$du = CdT + h'dp - pdv$$

---

* Since C_v is not used here, C is used for C_p.

One of the Maxwell relationships (the first) is

$$h' = -T\left(\frac{dv}{dT}\right)_p$$

from which

$$du = C\,dT - T\left(\frac{dv}{dT}\right)_p dp - p\,dv \tag{1}$$

which except for the u involves only quantities quite familiar in the laboratory, and is readily applied to the expansion experiments being considered.

In the *porous plug* experiment, the system is insulated from heat exchanges but not from work transfers, so that the condition to be satisfied is

$$u + pv = h = \text{constant}$$

and imposing this condition on the general equation (1) gives very easily the well known equation

$$C\mu = C\left(\frac{dT}{dp}\right)_h = T\left(\frac{dv}{dT}\right)_p - v \tag{2}$$

In the *free expansion* experiment, the system is isolated and neither work nor heat may be transferred across the boundary. That is, the energy of the system remains constant, or

$$u = \text{constant}$$

Imposing this condition on Eq. (1) gives

$$C\eta = C\left(\frac{dT}{dp}\right)_u = \left[T\left(\frac{dv}{dT}\right)_p - v\right] + \left(\frac{d(pv)}{dp}\right)_u \tag{3}$$

or

$$C\eta = C\mu + \left(\frac{d(pv)}{dp}\right)_u \tag{4}$$

which is a very simple relationship between the two coefficients η and μ. It is a precise statement of the readily recognized experimental situation, namely that the difference between the porous plug and the free expansion situations is the external work factor. It says that for unit change of pressure (dp) the quantity of heat ($C\,dT_u$) required to keep the temperature (T) constant in the free expansion experiment is equal to the heat ($C\,dT_h$) required in the similar porous plug expansion experiment, plus the heat $\left(\frac{d(pv)}{J}\right)_u$ equivalent to the change of pv in the free expansion experiment.

While Eq. (2) may evidently be used for computing μ, it is not very serviceable, since the term $\left[T\left(\frac{dv}{dT}\right)_p - v\right]$ is a small difference between larger experimental quantities. This applies also in Eq. (3) and moreover the variation of C with temperature and pressure has not been measured at all adequately. Conversely, if μ be known experimentally it offers an excellent method for calculating either $\left(\frac{dv}{dT}\right)_p$ or v.

Eq. (4) may readily be put in a form very suitable for computation, using the data for μ. Since there are only two free variables, if (pv) be chosen as a dependent variable, one can write

$$d(pv) = \left(\frac{d(pv)}{dp}\right)_T dp + \left(\frac{d(pv)}{dT}\right)_p dT \tag{5}$$

which holds generally and will therefore hold for the free expansion experiment where u = constant, or

$$\left(\frac{d(pv)}{dp}\right)_u = \left(\frac{d(pv)}{dp}\right)_T + \eta\left(\frac{d(pv)}{dT}\right)_p \tag{6}$$

and substituting this in (4) gives

$$\eta\left[C - \left(\frac{d(pv)}{dT}\right)_p\right] = C\mu + \left(\frac{d(pv)}{dp}\right)_T \tag{7}$$

The variation of (pv) as a function of p and of T is a very common way of expressing the properties of a gas. Such tabulations may readily be used to supply these two partial differential coefficients, and with C spread over the pressure range by the use of the isenthalpic curves (see first paper[1]), η may be readily calculated. Moreover, if one carries out the indicated differentiation (7) yields

$$\eta\left[C - p\left(\frac{dv}{dT}\right)_p\right] = C\mu + p\left(\frac{dv}{dp}\right)_T + v \tag{8}$$

in which however the second and third terms on the right give again the small difference between larger experimental quantities.

Also if in (8) one substitutes the values of μC from (2), there results

$$\eta\left[C - p\left(\frac{dv}{dT}\right)_E\right] = T\left(\frac{dv}{dT}\right)_p + p\left(\frac{dv}{dp}\right)_T \tag{9}$$

It might be observed that it is not required in this argument that the system be homogeneous, that is, of one phase only, though the physical meaning of the coefficients may differ in the two cases. This situation arises, for example, in this work where the isenthalpic curves cross the vapor pressure area of a several component system.

9. Experimental Results, Isenthalps.

The data from the experiments are given in Tables 1–12. The separate Tables are referred to by the approximate bath temperature. In each Table the data is grouped under letters to indicate the group readings (runs) made at one attempt. The last reading of the temperature and pressure in a run (numbered serially) is the bath temperature and the inlet high pressure. The temperatures are all reduced to the hydrogen Centigrade scale. The pressures are all in atmospheres (76 cm. mercury at 0° C.) and are in absolute terms, that is above zero not above atmospheric. The plug used is referred to by number. In general all the data are in duplicate agreeing with each other and taken with a different plug and rate of flow in the separate runs. The rate of flow is not given and was generally not recorded, care being merely taken to insure that the rates were different and neither excessively large or small. Each run has a particular plotting symbol so that the points may be distinguished on the plot.

The data are plotted in Fig. 3 using an unbroken pressure scale as abscissa but a temperature scale as ordinate with gaps in the scale to economize in the area needed. This shifts the curves out of their natural relation to each other and account must be taken of it when making comparisons. Reference to the earlier article will show immediately that the two series of curves fit together precisely—the change of position, of slope, and of curvature is regular and continuous. The growing steepness and curvature with falling temperature in the earlier work continues here, with maximum steepness at the lower end of the −85° C. curve approaching 1.6° C./atm. The curvature gradually concentrates towards the middle of the curve and increases so that while the lower end is still growing steeper, the upper end reverses its trend and grows flatter. The sharpened bend or knee moves down the curves until it fades out under and into the liquifaction curve. The data for this vapor pressure area as plotted in Fig. 3 are taken from the work of Kuenen and Clark[6] and of Dodge and Dunbar.[7] In the case of air, the width of this saturation area is so small that any attempt to follow by experiment these isenthalpic curves within this area will be hardly profitable.

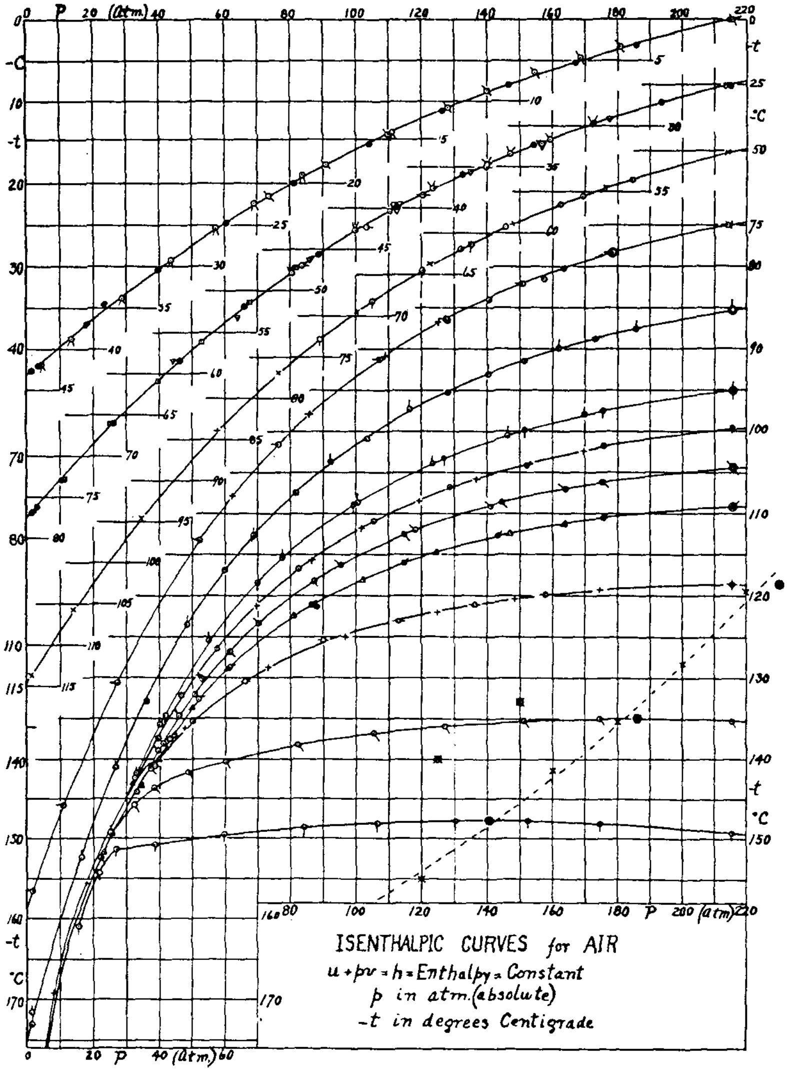

FIGURE 3.

It will be observed in Fig. 3 that the curves actually run into the saturation area, as they should, except in the lowest few points on the $-150°$ C. curve. These lowest two curves have only one run each—time failed at the close of the year. Also this $-150°$ C. curve was irregular in the way the equilibrium temperature was approached. It sometimes required half an hour before the drift had slowed down so as to be no longer observable while in the rest of the work five minutes was sufficient. This shows also in the μ for this curve which is the most irregular of all this lowest temperature group.

It should be noted also that the low end of the $-75°$ and $-85°$ C. curves are also determined by only one run. It proved so extremely difficult to avoid clogging of the plug with these large drops of temperature that when such curves as shown were obtained after many trials and the upper half or so was confirmed by another run, it was considered sufficient.

10. Locus of Maxima $\left(\frac{\Delta T}{\Delta P}\right)_h = \mu = 0$

The progressive flattening of the upper end of the curves, Fig. 3, proceeds until the sign of the slope reverses and on three of the curves the location of the maximum is marked by a cross surrounded by two small circles. The plot of μ,—the slope of these curves, as described later—against T at constant p in Fig. 6 gives another set of points (put in with x) on this locus of maxima, and the dashed curve in Fig. 3 is drawn through the group. The other two points put in with circles over a cross are the data taken by Hausen and reported by Knoblauch.[8] The position of the maxima on such flat curves is very difficult to locate but the divergence between Hausen's data and these here is larger than the apparent experimental errors. On account of the care taken in the present work in pressure and temperature regulation and duplication with different rates of flow (in the other curves), the probabilities of error are less than with Hausen's procedure.

Fig. 4 is the same as in the earlier article[1] (Fig 11 there) except that the lower branch of the unnamed curve is now drawn through the points just determined. The general aspect of the situation as discussed in the earlier paper is not changed. The area enclosed by the loop as well as the probable maximum pressure is increased slightly. The whole area can still be explored experimentally by means now available.

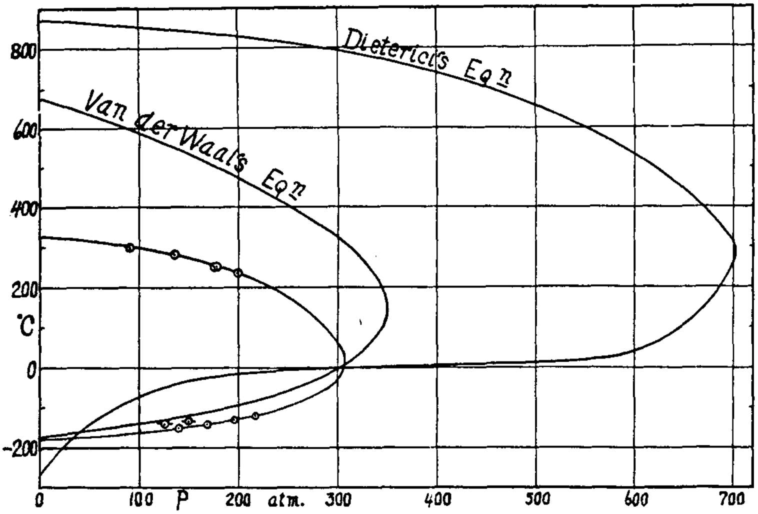

FIGURE 4. Loci of Maxima.

11. JOULE-THOMSON COEFFICIENT μ.

As in the previous paper[1] the numerical values of μ are obtained by taking the ratio of successive differences of t and p for each run. These values of μ were then plotted against the average value of the pressure to give the set of curves of Fig. 5. They are plotted each to the same abscissa zero but the ordinate μ scale is broken to separate these curves. It will be observed that the curves shift both linearly and angularly, positively and negatively in each case, so that the normal plotting leads to inextricable confusion among curves and points.

Evidently while taking the first differential has increased the variation and consequent uncertainty, nevertheless the position of each of these curves is fixed within fairly narrow limits. To lessen the uncertainty as much as possible, the procedure described in the earlier work was again followed but even more thoroughly. The values of μ from the curves of Fig. 5 were used to reproduce the curves of Fig. 3. The position and curvature of the curves of μ were shifted slightly until they satisfied the criterion, that is, until by starting at a middle point of a curve of Fig. 3, a numerical integration of the values of μ reproduced the curve within the experimental error. This was a very long tedious numerical process but it added immensely to the certainty of the μ curves. The 0° and $-25°$ curves have much more data but it is less consistent than the following curves where the control of P_2 was improving due to better purification of the compressed air and finally to the actual control of P_2. It is also evident that this process of making the μ curve agree with the integral curves has in no case made the curve inconsistent with the plotted points.

The curves of Fig. 5 are still isenthalps like those in Fig. 3 from which they are derived. To change the data to isopiestics the value of μ for a set of integral values of p were picked off and the values of t corresponding to the p's were read from Fig. 3. In Fig. 6 these values of μ are plotted as a function of t at constant p. To complete the set of curves the corresponding values of μ and t for the range above room temperature are included. Since the curves run so far along the t axis the diagram is cut in two parts and these placed to save space.

It will be observed that the two groups of data merge with each other without any need for adjustment. The values also drop very excellently on smooth curves. At high temperatures the value of μ for all pressures is small, becoming negative for the highest pressures shown. The trend of the curves shows very definitely that μ will be negative for all these pressures at temperatures less than 100° C. above those shown. This agrees with the discussion on Fig. 4 above.

As the temperature falls μ increases with increasing rapidity for all pressures but the more strongly for the lower pressures. Within 100° C. of the critical temperature this increase of μ changes to a decrease, for the higher temperatures, giving flat maxima. As these maxima are followed to the lower pressures and consequent lower temperatures, they become sharper and sharper peaks until the curve suddenly fails to turn down and continues rising apparently indefinitely. The last maximum must be a sharp cusp, and the situation there is very peculiar both in the diagram and with respect to the physical state of the material.

Corresponding to the steepness at the maximum the left hand side falls with increasing steepness until apparently the critical pressure is reached. If these curves were for a single component (pure) material one could say confidently that for pressures below the critical pressure μ shows no maxima but continues to rise, as appears to be the case here.

The fall on the left of the maxima carries the values of μ down to

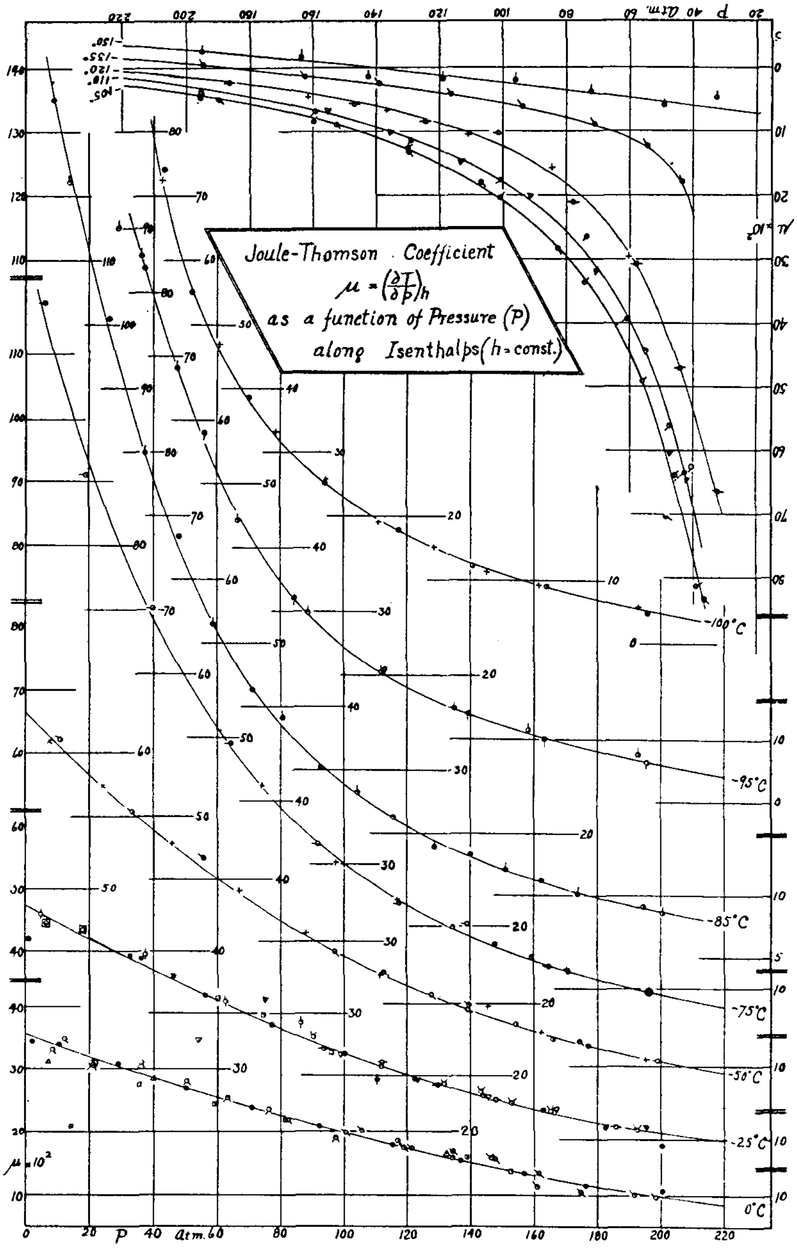
Joule-Thomson Coefficient
$\mu = \left(\frac{\partial T}{\partial p}\right)_h$
as a function of Pressure (P)
along Isenthalps (h = const.)
-150°
-135°
-120°
-118°
-105°
-100°C
-95°C
-85°C
-75°C
-50°C
-25°C
0°C
μ × 10²
P Atm.
0
20
40
60
80
100
120
140
160
180
200
220

FIGURE 5.

and below zero for the higher pressures, and unless the sudden curvature whose first part shows, interferes, it would appear as if all the curves would cross the zero line. This is of some interest as determining the lower branch of the curve of Fig. 4. It should preferably be attacked experimentally in the case of a pure material and one whose critical temperature is more easily reached, than is the case with air.

The curves of Fig. 3 run into the vapor pressure curve, some above and some below. If this vapor pressure curve was a line and not an area, then the isenthalpic curve which runs through the critical point should run through it parallel to the vapor pressure curve.[13, 14, 15] This of course is what one would expect from the general lay out. In Fig. 6 the value of μ_c ($p_c = 37.2$ atm. and $T_c = -140.6°$ C. for air[6]) should fall on the critical isopiestic where it crosses the critical temperature ordinate, and its value should agree with the slope of the vapor pressure curve, also at the critical state. The critical isopiestic runs so nearly vertical that its crossing point of the critical temperature ordinate is very uncertain. In view of the certainty of the above argument, it would be justifiable to draw this isopiestic through this point making

$$\mu_c = \left(\frac{dT_c}{dp_c}\right)_{v_c}$$

The average slope of the area near the critical condition was read from the plot of Fig. 3 giving

$$\left(\frac{dp_c}{dT_c}\right)_{v_c} = 0.63\,\frac{\text{atm.}}{1°\text{ C}}$$

and the point is put in as c on Fig. 6. This point falls almost on the 40 atm. isopiestic as drawn.

Air is of course not a single but a three component system, but one with a very narrow vapor pressure area and with the two critical points very close together,[6] so that it evidently makes a very good approximation to a one component system.

The fact that this point falls so high up on the P_c isopiestic means that the greater part of the adjustment in slope of the isenthalpics between the gas region and the liquid region takes place just below the critical state and under the saturation curve. This takes place as noted above by the sharp bend sliding down the isenthalpic curve till it is cut off entirely by the saturation curve.

It is also evident that if one were to collect the values of the slopes

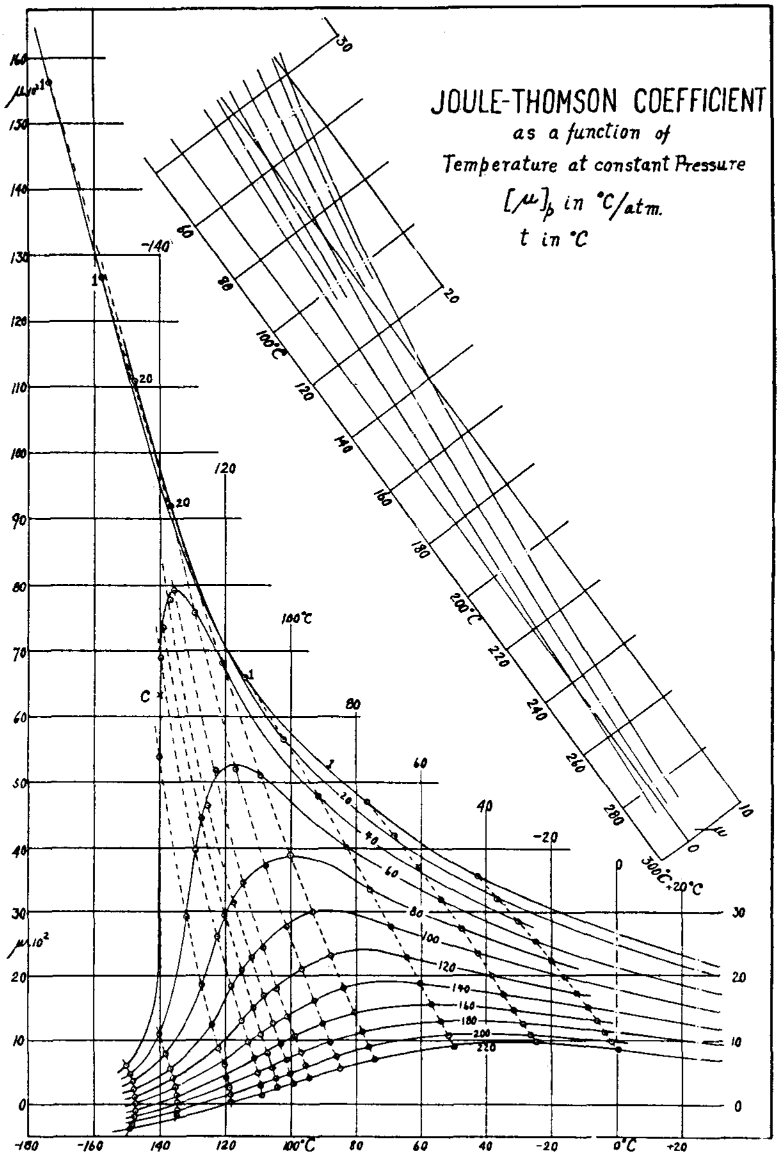
JOULE-THOMSON COEFFICIENT
as a function of
Temperature at constant Pressure
$[\mu]_p$ in °C/atm.
t in °C
$\mu \cdot 10^2$
$\mu \cdot 10^2$
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-180
-160
140
120
100°C
80
60
40
-20
0°C
+20
-140
120
100°C
80
60
40
-20
0
C
1
20
20
1
1
20
40
60
80
100
120
140
160
180
200
220
30
20
10
0
30
20
10
0
μ
60
80
100°C
120
140
160
180
200°C
220
240
260
280
300°C
+20°C

FIGURE 6.

of all the isenthalpic curves at the point where they cut the saturation curve (Fig. 3) these values would be the limiting values of μ, maxima for these isenthalps on both the liquid and vapor sides. In the plot of μ against T of Fig. 6, these values mark off an area which might be called the saturation area. At first it would appear as if none of the μ curves should cross this boundary, but it is to be observed that these plane diagrams are better considered as orthogonal projections from a three dimensional diagram in which the limit curve will be a line on the (μ, p, t,) surface. There is no reason why this surface, carrying the isopiestic curves, should not dip below this limit (saturation) curve as it apparently does in Hausen's formulation[12] and here where the $p = 1$ isopiestic crosses that for $p = 20$ (see Fig. 6). Hence, in the projection, these isopiestics can and do invade the area inside this limit curve.

For further use the values of μ for a set of integral values of pressure and temperature were picked off the large plot and are collected in Table 13. They cover only the low temperature range and must be combined with Table XI of the first paper[1] to cover the whole range measured.

12. Comparison with Hausen's Work.

The group of workers, Vogel, Noell, and Hausen,[12] with Prof. Knoblauch at Munich have done the only comparable work in this field with air. They have all used the same general methods and even the same apparatus, so that only the final worker, Hausen's, results need concern us here.

To compare the values of μ, the large scale plot of μ as a function of temperature at constant pressure, generously sent me by Hausen himself, was used to pick off the values of μ for 0, 100, and 200 atm. and the series of temperatures of the table, and are printed in italics in Table 14. The comparison values from the present work are printed in ordinary type. In parts of the field the agreement is excellent, about 1% near room pressure and temperature, but in other parts the difference goes in the extreme case to 300% for the small values. Even in the larger values the difference may amount to 50%. Since both groups of data have been smoothed to exclude as far as possible chance uncertainty of individual readings, there is not much purpose in a more detailed comparison than Table 14 affords.

In my first paper there is a discussion of the causes of uncertainty in Noell's work. Hausen used exactly the same plug arrangements. He calculates in some detail the heat leaks to be expected but he gives no experimental verification, for example, that the readings are independent of the rate of flow. Nor does he consider seriously the effects of velocity of flow, nor the effects of drifts from the hand regulation of pressure and of temperature. Until something is known experimentally with his apparatus about these sources of difficulty, I am inclined to suspect the causes of the divergence lie there.

13. Specific Heat, $C = C_p$.

In the first paper, p. 586, the method of calculating C was in error, in that the values of the factor for even values of temperature and pressure were picked off from the factor plot. This should have been done after the factors had been multiplied by the appropriate value of C on the one atm. line. These values for C have consequently been recalculated, but are substantially unaffected by a more correct smoothing.

To spread the values of C over the pressure-temperature range, it is necessary to know a series of values of C along a line cutting the isenthalpic curves of Fig. 3. Such a series of values would be sought first at $p = 1$ atm. over the temperature range. While this was excellent for the work above room temperature it is not very suitable for the present work, because, (1) a considerable portion of the curves do not extend to 1 atm. but end at the saturation curve, and (2) those curves which do extend to 1 atm. are widely spaced, run very steeply, and are perhaps the most uncertain experimentally. Above atmospheric pressure there are available Witkowski's[9] work up to 70 atm. and Jakob's[10] values calculated from the related properties of air. For the present purpose it would appear very profitable to use a method based on that used for water by H. L. Callendar[11] to measure the ratio of the specific heats at 100 atm. from room temperature to below the critical temperature.

Meanwhile the values given by Jacob[10] were used to calculate values of C at 100 atm. down to a lowest temperature of $-80°$ C. The calculated values are given in Table 15, which includes the Table XII from the previous paper unchanged except for the value at $p = 100$, $t = 0°$ C. which is shifted from 0.2804 to 0.2838.

The curves are of some interest but can profitably await values of C at such a pressure and temperatures as will serve to spread the values down to and below the critical temperature. Consideration of the curves of Fig. 3—whose meeting points mean a change of energy with no change of temperature or pressure—as well as the general theory of the critical state, make $C = \infty$ at $T = T_c$, $p = p_c$. (Compare also Burnett [15, 16] and Hausen.[12]) The data of Table 15 show the very rapid rise of C at the low temperatures, a rise which is different for each of the isopiestics.

14. Enthalpy h.

This quantity, h, is known by a variety of names—"intrinsic energy," "total heat," "thermodynamic potential," "χ function" (Gibbs)—as well as by a variety of symbols. The relation

$$[dh = Cdt]_p \quad \text{where} \quad C = \left(\frac{dq}{dt}\right)_p$$

has been used to calculate the difference in enthalpy between the constant enthalpy curves of Fig. 3 here, and Fig. 8 of the first paper. C varies so very slowly over the whole temperature range at 1 atm. pressure, that average values of C for the temperature step are quite sufficient. It is not feasible to evaluate the integration constant so an arbitrary zero has been selected at 0° C. and 1 atm.

In Table 16 is given the value for the enthalpy of each curve to as low a temperature as the value of C was available. The value of $C\Delta t$ for the same value of ΔT at 215 atm. varies over about $\pm$ 2%. These values of ΔT at 1 atm. are really the differences of considerably larger experimental values so that this treatment exaggerates the experimental errors. To lessen this erratic variation, the values were smoothed by plotting, being careful to keep the same total change in h.

It is evidently a routine matter to cross plot these h = const. curves of Fig. 3 here and of Fig. 8 of the first paper, to give either the variation of h with t at constant p (the usual "total heat diagram") or the variation of h with p at constant t. As no immediate use was to be made of them here, they are not given.

15. Rate of Change of Heat with Pressure, $\mu C = \left(\frac{dQ}{dp}\right)_h$.

Since the values of μ C are of considerable use in thermodynamic calculations and are used later here, the data for the low temperature range are collected in Table 17, which is therefore the complement of Table XIV of the first paper.[1] The values are obtained by multiplying together the value of μ in °C/atm. from Table 13 and C in cal./g.° C. from Table 15. To obtain these in C. G. S. mechanical units (cc./g.) they must be multiplied by

$$41.38 = \frac{4.188 \times 10^7}{13.59 \times 76 \times 980}$$

The values are negative in part of the field corresponding to the negative values of μ. In the general neighborhood of the critical state C varies rapidly and so here controls the variation of μC but over the rest of the field μ varies the more rapidly. On account of the uncertainty in the values of C below room temperature, the probable error in μC is largest there.

16. *pv* DATA FOR AIR.

In order to make use of Equations 2 and 7 for the computation of α_p and η it was necessary to look up the data on pv as a function of pressure and temperature. The data divide naturally into two groups, one above room temperature and the other below.

For the region 0° to 200° C. and 0 to 100 atmospheres use was made of the data of Holborn and Schultze.[17] The data were plotted on a large scale as isothermals, pv against p, and from these curves data were picked off for plotting isopiestics, pv against t. This allowed of selecting the values of pv and from this of the specific volume v, at the particular values of p and t used in the other tables. The values of v are collected in Table 18. The precision is probably better than that required for the computation of α_p.

The values of $\left(\frac{d(pv)}{dt}\right)_p$ and $\left(\frac{d(pv)}{dp}\right)_t$ required for use with Equation 14, are of course the slopes of these isopiestics and isothermals respectively. These slopes were consequently picked off by graphical means and smoothed by plotting and cross plotting. It was found necessary to interpolate for the 25° and 75° isothermal by interpolating the data for the slopes, since interpolating the original data led to quite inconsistent results for the slopes. The original data do not lead to very consistent curves, either on account of experimental error or because air has this character. The smoothing process was carried only far enough to smooth out chance errors in our treatment, but not far enough to interfere with the original character of the data. The data for the two coefficients are collected in Tables 19 and 20.

The low temperature pv curves had to be built up from a rather fragmentary collection of data from different workers. The data used were (1) that by Penning as given in International Critical Tables, Vol. 3, p. 10, (2) the isothermal given by Koch[18] at −79.1° C., (3) the isothermal at 0° from Holborn and Schultze,[17] (4) the points given by Witkowski[19] of zero slope of the isothermals. The isothermals so built up were cross plotted as isopiestics to allow of interpolating for the particular isothermals desired in the tables. These gave the values of pv which were used to obtain the specific volume data for the lower temperature range given in Table 18.

As before, these isothermals and the isopiestics plotted from them were used to obtain the values of the slopes $\left(\frac{d(pv)}{dp}\right)_t$ and $\left(\frac{d(pv)}{dt}\right)_p$ by graphical means. The resulting values were as before smoothed, but only to aid the graphical treatment, not to submerge the character of the data. Considerable extrapolation was necessary. The pressure coefficient is consequently apt to be in error, particularly at those values of p and t where the coefficient is small. On account of the data available the −75° isothermal and the 60 atm. isopiestic are the most reliable, and therefore also their respective coefficients (slopes). The effect of the interpolation and extrapolation necessitated by the fragmentariness of the data is evident in Table 19 in the 20 atm. row. At a constant pressure of 20 atm., the temperature coefficient should surely decrease continuously with rising temperature, instead of erratically as in the table. Nevertheless, the actual value of this coefficient appears to be reliable to 3 to 5% or better. The pressure coefficient is not quite as good.

17. COEFFICIENT OF VOLUME EXPANSION α_p.

Equation 2 above may be put in the form

$$\left[\frac{\mu C}{v} + 1\right]\frac{1}{T} = \frac{1}{v}\left(\frac{dv}{dT}\right)_p = \alpha_p \tag{10}$$

in which it is at once evident that $\frac{\mu C}{v}$ is proportional to the divergence of α_p from the reciprocal of T, and gives it as a measured difference. From which if

$$\frac{\mu C}{v} \gtreqless 0 \quad \text{then} \quad \alpha_p \gtreqless \frac{1}{T}$$

and as experimentally μ may be $\gtreqless 0$, it follows that α_p may be either larger or smaller than $\frac{1}{T}$. At the critical state both C and α_p become infinite.

At 1 atm $\frac{\mu C}{v}$ is small compared to unity; for example, at 0° C. it is 0.0034, so that 1% error in $\frac{\mu C}{v}$ introduces only 0.0034% error in α_p. The value of $\frac{1}{T_0}$ comes effectively from a coefficient measurement, but has a small μC correction, so that the variations in the value of α_p at these low pressures can be evaluated from these μC data with more precision than they can be measured directly.

As the pressure is increased v decreases very rapidly, so that at 100 atm. μC and v are about the same size, and hence the error in α_p is only slightly reduced from that in $\frac{\mu C}{v}$. As the difficulty in a direct measurement at this pressure is great, possibly the computed value would be still the better.

α_p has been computed (Table 21) using Eq. 17, μC in cal./g. atm. from Table 17, which is converted into cc./g. as described above and v from Table 18. It should be noted that these values of α_p are not averages over a range in temperature but are the differential values at the particular temperature and pressure specified.

18. FREE EXPANSION OR JOULE COEFFICIENT $\eta = \left(\frac{dT}{dp}\right)_u$.

Equation (7) above may be used readily for computing η and the values are detailed in Table 22. The necessary data for C were picked from Table 15; for $\left(\frac{d(pv)}{dT}\right)_p$ from Table 19 in L./g. atm. and changed to cal./g. ° C. by multiplying by 24.17; for μC from Table 17 and First Paper Table XIV; for $\left(\frac{d(pv)}{dp}\right)_t$ from Table 20 in L./g. atm. and changed to cal./g. atm. by multiplying by 24.17.

For the whole range the second term in the bracket runs about ⅓ of C, the two terms varying somewhat together. The last term on the right runs from about 5% of μC at $-75°$ C. and 140 atm. to 150% at $+200°$ C. and 100 atm: that is, in the range near the critical state where C grows very rapidly μC dominates, but where μ is small in the neighborhood of the inversion temperature μC becomes relatively unimportant. Where μC vanishes the second term is still strongly of account so that as far as can be inferred from this data η does not go to zero. This is of course the behavior to be expected from the kinetic theory in which the force between the molecules does not vanish except perhaps for very great separation, a case not even remotely estimable from the above data. In consequence of the relative sizes of the terms it appears that they all have material importance in fixing the value of η, and it is correspondingly difficult to estimate the precision with which η is known.

Evidently from Eq. 4, $\eta \gtreqless \mu$ according as $\left(\frac{d(pv)}{dp}\right)_u \gtreqless 0$. If one attempts to estimate $\left(\frac{d(pv)}{dp}\right)_u$ from the isothermal case $\left(\frac{d(pv)}{dp}\right)_T$, there arises the effect on (pv) of the temperature variation in the $(pv)_u$ case, which on account of the small variation of $(pv)_t$ may actually dominate. There are no measurements leading to a knowledge of the variation of $(pv)_u$, though it could be calculated from the data in this paper by using Eq. 4.

So far as I know there are no published experimental measurements of η. Joule's work led to no numerical values. It was tried in this laboratory by one of my students, E. V. Floyd, using air, and allowing it to expand from an inner vessel into the space between, which was previously evacuated. This made it possible to reduce the material sharing the change of temperature with the air, to less than 300 times the mass of the air. The interpretation of the experimental data is much complicated by the change of temperature of the two vessels' walls, due to their changes of stress. The serious mechanical difficulties in the construction of the vessel occupied most of the available year. The preliminary data obtained however was just what was expected but was neither elaborate enough nor sufficiently certain to justify separate publication. When opportunity offers the problem will be taken up again as it is decidedly advisable to check at least part of the data of Table 22 by direct experimental measurement.

Worthing[14] has calculated both μ and η, from Eq. 2 for μ and an equation which he derived by a cyclic argument for η. Both equations involve small differences in a way to magnify the error in the data. Table 23 shows the way his data compares with that in this paper. Considering the difficulties involved in his situation—none too trustworthy or abundant data, complex formula, involving small differences—the agreement is excellent.

H. Hausen[12] has also used his measurements of μ to calculate the numerical magnitude of a number of the physical properties of air, among which is the free expansion coefficient. His method of analysis is radically different from that used in this article, as he employs with great skill mostly cyclic arguments referring directly to real or ideal experiments. For his calculation he also requires the pv relations of air.

His values of η are given only in the form of small curves, and he claims only 10% accuracy, on account of the exaggerated effect of small errors in the graphical and numerical treatment. For comparison with Table 22, his values of η have been picked off these curves over the range of comparison only, and are given here as Table 22A. As will be observed, his values are almost uniformly larger than mine by at least 10%. The trends are quite similar—a small rise with pressure at low pressures, and a steady fall at higher pressures, as well as a fall with rising temperature when distinctly above the critical temperature.

19. ELASTIC COEFFICIENT $-\gamma = \frac{1}{v}\left(\frac{dv}{dp}\right)_t$ IN (ATM)$^{-1}$.

Equation (9) may be readily rewritten as

$$-\gamma = \frac{1}{v}\left(\frac{dv}{dp}\right)_t = \eta\left[\frac{41.38C}{pv} - \alpha_p\right] - \frac{T\alpha_p}{p}$$

This has been used to calculate the values of γ given in Table 24, using η from Table 22 in °C/atm., C from Table 15 in g.cal/° C, v from Table 18 in cc/g., and α_p from Table 21 in (°C.)$^{-1}$.

Numerically, of the two terms within the brackets on the right, α_p is usually about one quarter of the first term, while the term $\eta\left[\frac{C41.38}{pv} - \alpha_p\right]$ makes a small correction, 0.5% − 0.2% for the low pressures to 50% − 25% for the higher pressures, on the term $\frac{T\alpha_p}{p}$.

If the gas obeys Boyle's law, then γ becomes equal to 1/p. For comparison, the values of 1/p are given in the right hand column of Table 24. It will be observed that the tabulated values are in all cases quite close to the corresponding value of 1/p. Also these tabulated values fall slightly with rising temperature at all pressures, generally somewhat more rapidly at the lower temperatures, and generally rapidly enough that the irregularities do not obscure the drift. That is, at all the pressures shown the air is more compressible than the ideal gas at the lower temperatures and less compressible at the higher temperatures.

20. CONSTANT PRESSURE AIR SCALE.

In the first paper[1] the Kelvin scale temperature of the ice point was calculated as 273.15° K., using the available values of the average coefficient between the ice point and the steam point, and the values of μC for the same range. These corrections are now extended to the range covered by these experiments. The method used is that due to Buckingham,[20] which was used also by Hoxton.[21]

Eq. 2 above may be readily rewritten in the integral form[1]

$$\frac{v}{T} - \frac{v_0}{T_0} = \int_{T_0}^{T} \frac{C\mu dT}{T^2} \tag{11}$$

and this used to write the working equation

$$t_a - t = 0.7012\,\alpha t - TT_0\rho_0\,0.0413 \int_{T_0}^{T} \frac{\mu C}{T^2}\,dT \tag{12}$$

where T_0 is the ice point on the Kelvin scale already calculated from these data, and

$$T_0 = \frac{1}{\alpha} + 0.7012$$

where $\alpha = 0.0036708$ ($p = 760$ mm.). T is the temperature on the Kelvin scale so that $t_a = T - T_0$ and t is the temperature on the Centigrade air scale. $\rho = 1.293$ g/L at 760 mm. and 0° C.

To evaluate the integral use was again made of the relation

$$\mu C = \frac{A}{T} + B$$

which represents uC quite accurately over moderate ranges of temperature, as shown in the first paper, for temperatures above room temperature. The integration was performed in steps to cover this range

For the range below room temperature, μC plotted against $1/T$ shows decidedly more curvature so the integration was carried out by determining A and B from the plot. The data on μC for the low temperature range at 1 atm. are somewhat less reliable than at higher temperatures, as was shown by the lesser regularity of the values for the successive steps. It would appear also that the value of μ at 0° is somewhat low, as surmised also by O. C. Bridgman,[22] but re-examination of the data shows no present ground for altering the values. The data are given in Table 25, which gives also the data from Buckingham.[20]

These corrections apply to a thermometer using 760 mm. pressure, but it is possible to modify them without material error for a slightly different working pressure.

In Eq. (12) above

$$0.7012 = \frac{T_0(T_0 + 100)}{100\alpha}\rho_0 \int_{T_0}^{T_{100}} \frac{\mu C}{T^2}\,dT \tag{13}$$

so that ρ_0 is a factor in the right hand member of Eq. (12).

If the chosen new pressure is not sufficient to alter μC materially, only ρ_0 among these other quantities is altered, so that

$$\frac{(t - t_a)^{1}}{(t - t_a)^{11}} = \frac{\rho_0{}^{1}}{\rho_0{}^{11}} = \frac{p_0{}^{1}}{p_0{}^{11}}$$

or the ratio of the densities or pressures will give with quite sufficient accuracy the ratio of the corrections.

21. INTRINSIC ENERGY VARIATION WITH VOLUME. $\lambda = \left(\frac{du}{dv}\right)_T$.

In Eq. 1 above if one inserts the condition that the temperature remains constant, the result may be written

$$\lambda = \left(\frac{du}{dv}\right)_T = -T\left(\frac{dv}{dT}\right)_p\left(\frac{dp}{dv}\right)_T - p \tag{14}$$

$$= \frac{T\alpha_p}{\gamma} - p \tag{15}$$

where λ is therefore a function of both p and t.

This relation has been used to calculate λ given in Table 26 using α_p from Table 19 in (°C.)$^{-1}$ and γ from Table 24 in (atm.)$^{-1}$. λ is therefore in atm. The two terms on the right of Equation 15 are numerically nearly alike at the low pressures (0.6% to 0.08% different) but this difference increases with pressure until in the extreme case the first term is more than twice the second (at −75° C. and 140 atm.).

It will be noted that λ falls with rising temperature at all pressures, by about a factor of 10 in the temperature range covered. Since one of the terms in the definition of an ideal gas is that $\lambda = 0$, this fall of λ shows that the air is varying toward ideality rather rapidly over this temperature range.

On the other hand, λ grows with extreme rapidity with pressure increase, at all temperatures, by a factor of about 10,000 for the 100 atm. rise. In terms of the definition of ideality, this means that at the low pressures air is very close to the definition, but that it diverges very rapidly from it as the pressure is raised, seemingly more rapidly than it does from the pv = const. term of the definition.

Such a table of values for λ may evidently be used as a very convenient starting place in an attempt to estimate the law of force between molecules in the gas, as well as the actual forces. It is a very complicated problem and is unnecessarily difficult in this case on account of the presence of several molecular species, and of the complex nature of the molecules. A single atomed molecule (helium) of one species would be preferable.

22. CONSTANT VOLUME AIR SCALE.

Eq. 14 above may be used to calculate the corrections of the (air) scale to the Kelvin scale as well as the Kelvin temperature of the ice point. Using the general relation

$$\left(\frac{dv}{dt}\right)_p \left(\frac{dp}{dv}\right)_t \left(\frac{dt}{dp}\right)_v = -1$$

Eq. (14) may be written

$$\lambda = T\left(\frac{dp}{dT}\right)_v - p$$

in which the similarity in form to Eq. (2) is evident. This may be used[20] to calculate the corrections for the constant volume air thermometer. By dividing through by T^{-2} and rearranging

$$\frac{\lambda dT}{T^2} = d\left(\frac{p}{T}\right) \quad \text{or} \quad \frac{p}{T} - \frac{p_0}{T_0} = +\int_{T_0}^{T} - \lambda d\frac{1}{T} \qquad (16)$$

to which the condition v = const. still adheres. Hence to integrate this, one must pick the values of λ at the desired temperatures, each at such a pressure that the volume remains constant. These are then to be plotted against T^{-1} and the area under the curve measured.

In Eq. 14 if p be allowed to approach zero, then $\left(\frac{dp}{dv}\right)_t \doteq 0$ and $\therefore$ $\lambda \doteq 0$; therefore a plot of the curve, λ against p at constant temperature, starts from the origin. The actual plot shows that λ grows very rapidly from the origin, the first part of the curve being only slightly curved, so that over a range of 0.5 to 1.6 atm. one may use $\lambda : p$ and determine the proportionality by the value of λ at 1 atm.

As will appear from the size of the correction, 1% uncertainty in the values of λ introduces about 1% in the correction, and this less than 0.01° in T_0. The range over which p is to be used is from 0.5 to 1.6 atm., in which the general gas law will give proportionalities well within 1% uncertainty. Hence the pressures were calculated using $p : T$ for the series of temperatures from -100 to $+200°$ C., using $p = 1$ atm. at 0° C. Using these values of p the corresponding values of λ were calculated as indicated above. These λ's were then plotted as a function of T^{-1} and a smooth curve drawn through the points. There is considerably more irregularity among these points than in the points for μ, so that the uncertainty here may run up to 5%. The curvature is not large, so that the integral of $\lambda d\frac{1}{T}$ may be taken assuming the curve a straight line over 25° C. steps from 0° C. to 100° C.; these integrals may be computed very simply by using

$$-\int_1^2 \lambda d\frac{1}{T} = \left(\frac{\lambda_1 + \lambda_2}{2}\right)\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

which gives 23.09×10^{-7} between the ice point and the boiling point.

The constant volume air scale is defined by the relation

$$p : t \quad v \text{ and } m \text{ constant}$$

and therefore

$$T = T_0\frac{p}{p_0}$$

Let $T_0 =$ ice point, $T = T_0 + 100 =$ boiling point, $p = p_0(1 + \beta 100)$. Eq. (16) may then be written

$$\frac{p_0(1 + 100\beta)}{T_0 + 100} - \frac{p_0}{T_0} = 23.09 \times 10^{-7} \times \frac{p_0}{1}$$

The best available value of β for air[20] is Chappuis', namely 0.00367442 per degree C. measured at $p_0 = \frac{1002}{760}$ atm. The λ integral (23.09×10^{-7}) is for $p_0 = 1$ atm., but since the individual values of λ are proportional to the pressure, the integral is also. Hence, the relation may be written

$$T_0 = \frac{1}{\beta} + \frac{23.09 \times 10^{-7}\, T_0(T_0 + 100)}{100\beta}$$

in which the second member on the right is a small correction term in which $T_0 = 273$ is sufficient.

$$\therefore \quad T_0 = 272.152 + 0.640 = 272.79^\circ \text{ K}$$

When this is compared with $T_0 = 273.15$ calculated in the earlier paper, it is nearly 0.4° too small. To take up this discrepancy by changing λ requires adding more than 50% to the above value of λ. The errors of the calculation save for the possible gross blunder, could not account for 50%. To put the burden on the value of β would require an error of about 1 part in 700 which, in view of the care used, seems unlikely except for some unsuspected source of error. If one looks for this in the difference of gas absorption on the walls, the discrepancy appears large to account for this way, and on simple considerations would appear more likely to make β relatively small compared to α; that is, the resulting correction would be of the wrong sign.

It might be noted also that Buckingham[20] gives the corrections for the constant volume nitrogen thermometer as decidedly smaller than for the constant pressure case. If this applies also over the range $T = 0$ to $T =$ ice point, then the correction to $\frac{1}{\beta}$ should be smaller than the correction to $\frac{1}{\alpha}$. But the Chappius' values for α and β require just the opposite; that is, the correction to $\frac{1}{\beta}$ must be the larger. As far as this is valid, it would be in agreement with the λ result above and seem to throw the burden on Chappius' value of β.

In view of this discrepancy, it has not appeared profitable to calculate the corrections to the constant volume air scale, but they will be about ⅔ those to the constant pressure scale.

23. Conclusion.

This finishes the work on air for the present, except that this data is being used to supply part of the material for an article on the liquifaction of air.

A list of the topics covered will be found on the first page.

I wish to acknowledge again, as in the first paper, the receipt of a grant from the Rumford Fund of the American Academy which was used for the purchase of the unglazed porcelain plugs use practically throughout the work, and contributing very materially to its success.

My acknowledgments are also due to my two effective helpers, Dr. J. H. Webb who except for his own modesty should have appeared as a co-author, and Mr. Harold Osterberg who helped in the computing and who is helping to gather the next experimental data. My thanks are due to both as energetic able partners in this work.

In the beginning of this attack on the Joule-Thomson problem years ago, air was selected as the working fluid for very obvious reasons —availability, cheapness, innocuousness of small leaks, etc. So that this attack is to be looked upon as a test out of the methods as well as an attempt to supply such data for air. Examination of the data taken as the work progressed will show a steady improvement as both the physical and mental situation came more and more under effective control. If the measurements were to be repeated, the numerical data could be improved very materially. Technically, air is a very important substance, but the need for high precision there is not great and Dr. Hausen's data as well as mine should suffice. Scientifically air is being increasingly neglected in favor of the pure gases, so that for example the data on α and β used above are a good many years old.

Consequently the next move is to measure the pure gases. This involves using a low pressure reservoir as well as the high, and the use of a closed, tight system. This work has been pushed while the above computations have been in hand, so that the system is nearly ready for work. The Bureau of Mines is supplying helium as the first pure gas to be measured.

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TABLE 1.

A

Plug #51 Symbol ☌

No.	p	$-t$
1	73.5	21.56
2	91.2	17.69
3	109.7	14.02
4	128.1	10.80
5	140.7	8.67
6	154.4	6.51
7	168.4	4.63
8	180.9	3.35
9	215.8	0.0

B

Plug #41 Symbol ⊕

No.	p	$-t$
1	1.2	42.76
2	3.0	42.10
3	17.9	37.02
4	39.6	30.39
5	60.5	24.80
6	81.3	19.87
7	103.9	15.19
8	126.4	11.18
9	146.7	8.04
10	167.0	5.31
11	185.3	3.20
12	215.2	0.0

C

Plug #51 Symbol ☊

No.	p	$-t$
1	3.8	42.00
2	13.2	38.78
3	28.8	33.81
4	43.4	29.25
5	57.2	25.39
6	69.0	22.39
7	83.6	18.94
8	111.0	13.72

TABLE 2.

A

Plug #41 Symbol ⊕

No.	p	$-t$
1	1.3	76.90
2	2.9	76.23
3	10.3	72.94
4	26.2	66.06
5	46.2	58.38
6	66.0	51.86
7	88.4	45.57
8	112.6	39.86
9	132.7	35.92
10	154.0	32.36
11	172.4	29.67
12	193.5	27.15
13	215.2	25.20

B

Plug #35 Symbol ▽

No.	p	$-t$
1	44.3	58.49
2	64.0	53.30
3	86.1	46.23
4	112.3	40.09
5	134.9	35.73
6	156.8	32.12
7	177.6	29.27
8	213.6	25.01

C

Plug #49 Symbol ♉

No.	p	$-t$
1	80.6	47.86
2	100.1	42.73
3	123.9	37.63
4	139.9	34.63
5	147.0	33.39
6	159.1	31.66
7	171.9	29.82
8	213.6	25.01

D

Plug #49 Symbol -⊙-

No.	p	$-t$
1	84.3	47.02
2	103.5	42.34
3	120.6	38.56
4	139.4	35.08
5	156.7	32.29
6	215.6	25.22

E

Plug #49 Symbol ⊡

No.	p	$-t$
1	1.8	76.76
2	10.8	72.80
3	26.3	66.07
4	39.5	60.90
5	52.9	56.11
6	67.3	51.46
7	81.9	47.12
8	110.4	40.40

TABLE 3.

A

Plug #35 Symbol ×

No.	p	$-t$
1	1.2	113.76
2	13.9	105.76
3	34.3	94.57
4	57.6	83.94
5	76.2	76.92
6	100.2	69.42
7	122.7	63.82
8	147.9	58.89
9	176.3	54.51
10	214.2	50.33

B

Plug #49 Symbol ⊙

No.	p	$-t$
1	131.9	61.94
2	146.1	59.23
3	162.4	56.51
4	169.6	55.48
5	184.4	53.50
6	213.6	50.33

C

Plug #49 Symbol ♀

No.	p	$-t$
1	89.0	72.83
2	105.2	68.24
3	120.2	64.48
4	135.0	61.30
5	213.6	50.33

D

Plug #49 Symbol \⊙

No.	p	$-t$
1	1.0	113.58
2	1.3	113.20
3	20.2	101.56
4	46.6	88.67
5	64.4	80.94
6	215.2	50.86

TABLE 4.

A

Plug #35 Symbol -⊙

No.	p	$-t$
1	1.6	156.53
2	10.8	145.73
3	27.3	130.72
4	52.2	113.26
5	76.1	101.56
6	107.3	91.19
7	127.4	86.43
8	150.7	82.13
9	178.5	78.35
10	214.2	75.00

B

Plug #49 Symbol ⊙

No.	p	$-t$
1	127.8	86.54
2	140.6	84.02
3	157.4	81.59
4	163.4	80.27
5	178.3	78.37
6	213.6	75.00

C

Plug #49 Symbol +

No.	p	$-t$
1	62.2	107.89
2	85.8	97.86
3	108.8	90.91
4	125.1	86.98
5	215.2	75.00

TABLE 5.

A

Plug #49 Symbol ⊙

No.	p	$-t$
1	1.3	172.95
2	16.6	152.32
3	35.9	132.85
4	59.9	116.85
5	81.9	107.43
6	103.3	100.90
7	128.1	95.28
8	151.4	91.42
9	173.0	88.75
10	215.5	85.30

B

Plug #48 Symbol ♁

No.	p	$-t$
1	1.3	171.58
2	26.3	141.04
3	48.3	123.47
4	68.8	112.61
5	92.1	103.66
6	116.4	97.24
7	140.2	93.01
8	161.9	89.91
9	185.6	87.50
10	215.5	85.28

TABLE 6.

A

Plug #49 Symbol ♁

No.	p	$-t$
1	25.1	149.22
2	32.7	141.80
3	39.8	135.72
4	54.9	125.45
5	77.5	115.43
6	100.4	108.60
7	123.3	103.90
8	146.3	100.47
9	169.9	97.88
10	215.5	94.87

B

Plug #48 Symbol ♀

No.	p	$-t$
1	32.5	142.45
2	41.8	134.66
3	69.8	118.43
4	98.9	109.10
5	126.9	103.19
6	151.4	99.77
7	175.3	97.39
8	215.5	94.87

TABLE 7.

A

Plug #49 Symbol +

No.	p	$-t$
1	7.9	169.20
2	18.0	155.58
3	33.3	143.06
4	51.7	129.74
5	69.8	121.24
6	86.4	115.73
7	101.8	111.76
8	119.3	108.44
9	136.8	105.80
10	153.1	103.96
11	169.6	102.43
12	215.5	99.80

B

Plug #48 Symbol ⊙

No.	p	$-t$
1	39.6	137.41
2	46.6	132.22
3	57.2	126.38
4	82.3	116.69
5	105.3	110.92
6	128.8	106.74
7	152.3	103.85
8	175.4	101.77
9	215.5	99.62

TABLE 8.

A			B		
Plug #49		Symbol ⊙	Plug #48		Symbol ♂
No.	p	$-t$	No.	p	$-t$
1	33.0	144.16	1	37.3	141.26
2	39.4	138.84	2	41.1	138.18
3	46.0	134.66	3	50.8	131.98
4	52.8	130.18	4	61.3	126.83
5	70.2	123.35	5	87.1	118.19
6	95.3	116.25	6	114.9	112.54
7	118.2	112.12	7	144.7	108.76
8	141.2	109.09	8	175.1	106.23
9	163.8	107.07	9	215.5	104.38
10	215.5	104.38			

TABLE 9.

A			B		
Plug #49		Symbol △	Plug #48		Symbol ♂
No.	p	$-t$	No.	p	$-t$
1	23.0	151.76	1	38.3	140.52
2	34.4	143.42	2	43.1	137.52
3	39.8	139.96	3	51.9	132.58
4	44.4	136.99	4	61.2	128.67
5	49.9	133.67	5	86.4	121.02
6	60.7	128.89	6	114.8	116.02
7	81.0	122.41	7	143.2	112.78
8	102.0	118.09	8	175.4	110.58
9	124.3	114.81	9	215.5	109.17
10	146.9	112.50			
11	163.6	111.35			
12	215.5	109.17			

TABLE 10.

A			B		
Plug #49		Symbol -⊙-	Plug #48		Symbol +
No.	p	$-t$	No.	p	$-t$
1	25.6	149.37	1	47.6	136.18
2	38.5	140.81	2	73.1	128.66
3	50.1	135.36	3	96.8	124.95
4	66.1	130.45	4	124.9	122.02
5	90.1	125.40	5	148.5	120.42
6	112.9	123.08	6	174.5	119.25
7	136.1	121.12	7	215.5	118.60
8	157.9	119.88			
9	215.5	118.60			

TABLE 11.

A

Plug #48 Symbol ⊙

No.	p	$-t$
1	23.2	152.40
2	32.4	145.84
3	38.2	143.59
4	48.7	141.72
5	60.0	140.33
6	82.2	138.16
7	105.6	136.75
8	127.1	135.86
9	151.1	135.28
10	174.3	134.97
11	215.5	135.24

TABLE 12.

Plug #48 Symbol ♀

No.	p	$-t$
1	15.6	160.86
2	21.7	154.34
3	26.8	151.30
4	38.5	150.75
5	59.9	149.51
6	84.4	148.59
7	107.7	148.15
8	130.4	147.78
9	152.7	147.75
10	174.7	148.15
11	215.5	149.28

TABLE 13.

μ (low temps.).

P	−150° C.	−140° C.	−120° C.	−100° C.	−75° C.	−50° C.	−25° C.
1		.9510	.707	.5750	.4620	.3755	.3160
20		.9750	.705	.5535	.4380	.3565	.2965
40	+.0620	.5700	.672	.5210	.4105	.3325	.2750
60	+.0440	.1105	.522	.4700	.3765	.3080	.2540
80	+.0315	.6800	.294	.3870	.3330	.2785	.2330
100	+.0190	.0435	.1650	.2845	.2870	.2470	.2115
120	+.0070	.0285	.1015	.1990	.2705	.2135	.1865
140	−.0030	.0155	.0845	.1415	.1960	.1815	.1640
160	−.0125	+.0020	.0460	.1030	.1475	.1550	.1435
180	−.0215	−.0080	.0285	.0745	.1165	.1305	.1250
200	−.0280	−.0175	+.0130	.0490	.0920	.1100	.1075
220	−.0385	−.0280	−.0150	.0310	.0685	.0935	.0975

TABLE 14.

μ from Table 13 in Roman type.
μ from Hausen's work in Italic type.

P	−150° C.	−140° C.	−120° C.	−100° C.	−75° C.	−50° C.	−25° C.	0° C.	+25° C.
1		.971	.707	.575	.462	.376	.316	.266	.227
0		*1.028*	*.796*	*.642*	*.501*	*.399*	*.327*	*.269*	*.224*
100	+.019	.044	.165	.285	.287	.247	.215	.178	.152
100	*−.006*	*.015*	*.164*	*.244*	*.166*	*.168*	*.127*	*.086*	*.055*
200	−.028	−.018	−.013	+.049	.092	.110	.108	.084	.073
200	*−.035*	*−.030*	*−.007*	*+.028*	*.075*	*.100*	*.110*	*.095*	*.088*

TABLE 15.

C_p as function of p and t g. cal/°C.

P	−100° C.	−75° C.	−50° C.	−25° C.	0° C.	+25° C.	+50° C.	+75° C.	+100° C.	+150° C.	+200° C.	+250° C.	+280° C.
1	.2385	.2390	.2394	.2399	.2405	.2410	.2415	.2419	.2424	.2434	.2443	.2453	.2458
20	.2757	.2630	.2556	.2514	.2492	.2487	.2480	.2475	.2470	.2466	.2463	.2468	.2471
60		.3184	.2883	.2744	.2656	.2627	.2603	.2581	.2562	.2532	.2512	.2500	.2492
100		.3940	.3264	.2979	.2838	.2760	.2717	.2681	.2650	.2602	.2565	.2536	.2519
140		.4427	.3561	.3171	.2985	.2873	.2816	.2767	.2725	.2658	.2607	.2566	.2544
180			.3747	.3317	.3093	.2960	.2898	.2840	.2790	.2707	.2644	.2596	.2569
220			.3780	.3393	.3183	.3020	.2956	.2893	.2838	.2748	.2678	.2622	.2593

TABLE 16.

Enthalpy, $h = u + pv$, g. cal.

Curve	h
280	78.53
250	70.68
200	57.41
150	43.83
100	29.87
75	22.70
50	15.36
25	7.82
0	0.00
−25	−8.22
−50	−17.07
−75	−27.07
−85	−31.57

TABLE 17

μC.

From Tables 13 and 14 g. cal/g. atm.

P	−100° C.	−75° C.	−50° C.	−25° C.	0° C.
1	.137	.1104	.0899	.0758	.0640
20	.153	.1152	.0911	.0745	.0622
60		.1199	.0888	.0697	.0569
100		.1131	.0806	.0630	.0506
140		.0868	.0646	.0520	.0431
180			.0489	.0415	.0348
220			.0353	.0331	.0258

TABLE 18.

SPECIFIC VOLUMES IN $\left(\frac{cc}{g}\right) \times 10^{-3}$.

P(atm.)	−100° C.	−75° C.	−50° C.	−25° C.	0	+25° C.	+50° C.	+75° C.	+100° C.	+150° C.	+200° C.
1	.5014	.5578	.6212	.7007	.7735	.8439	.9150	.9862	1.0574	1.1989	1.3408
20	.02283	.02611	.03017	.03419	.03859	.0420	.04567	.04927	.05298	.06025	.06745
60		.00805	.00959	.01114	.01253	.01394	.01524	.01655	.01779	.02034	.02282
100		.00450	.00561	.00657	.00751	.00837	.00920	.01005	.01083	.01237	.01392
140		.00318	.00395	.00470							
180			.00316	.00371							

TABLE 19.

$\left(\frac{d(pv)}{dt}\right)_p \times 10^3$ v is in L/g, p in atm., t in °C.

P	−100° C.	−75° C.	−50° C.	−25° C.	0° C.	+25° C.	+50° C.	+75° C.	+100° C.	+150° C.	+200° C.
1	2.835	2.835	2.835	2.835	2.835	2.835	2.835	2.835	2.835	2.835	2.835
20	3.196	3.039	3.094	3.094	2.943	2.942	2.938	2.925	2.914	2.908	2.908
60		4.093	3.551	3.318	3.117	3.115	3.099	3.068	3.023	2.983	2.978
100		4.720	4.124	3.713	3.512	3.441	3.344	3.210	3.119	3.067	3.054
140		4.880	4.200	3.838							
180			4.038	3.814							

TABLE 20.

$+\left(\frac{d(pv)}{dp}\right)_t \times 10^4$ v IN L/g, AND p IN ATM.

P	−100° C.	−75° C.	−50° C.	−25° C.	0° C.	+25° C.	+50° C.	+75° C.	+100° C.	+150° C.	+200° C.
1	−24.74	−14.12	−11.36	−8.498	−4.33	−2.57	−1.04	0.008	0.92	2.70	4.21
20	−23.52	−13.31	−9.292	−6.653	−3.73	−1.90	−0.37	0.71	1.66	3.31	4.52
60		−10.83	−5.570	−4.023	−1.91	−0.28	+1.07	2.16	3.08	4.33	5.18
100		−5.106	−2.166	−1.248	+0.62	+1.67	2.60	3.47	4.25	4.95	5.85
140		+1.778	+1.161	+1.161							
180			+4.251	+3.482							

TABLE 21.

$\alpha_p \times 10^3$ (per °C.)

P(atm.)	−100° C.	−75° C.	−50° C.	−25° C.	0° C.	+25° C.	+50° C.	+75° C.	+100° C.	+150° C.	+200° C.
1	5.84068	5.08804	4.50814	4.04838	3.67168	3.36301	3.10091	2.87694	2.68326	2.36506	2.11399
20	7.374	5.967	5.041	4.393	3.905	3.528	3.218	2.961	2.743	2.397	2.131
60		8.161	6.198	5.073	4.348	3.828	3.428	3.108	2.848	2.450	2.157
100		10.30	7.298	5.631	4.681	4.048	3.577	3.213	2.921	2.484	2.169
140		10.75	7.514	6.051							
180			7.351	5.895							

TABLE 22.

$$\eta = \left(\frac{dT}{dp}\right)_u \text{ in } ^\circ\text{C./atm.}$$

P	−100° C.	−75° C.	−50° C.	−25° C.	0° C.	+25° C.	+50° C.	+75° C.	+100° C.	+150° C.	+200° C.
1	.455	.448	.365	.322	.311	.281	.249	.220	.198	.172	.145
20	.482	.438	.379	.331	.299	.270	.244	.218	.197	.165	.140
60		.427	.372	.309	.275	.242	.228	.207	.188	.156	.133
100		.360	.301	.288	.244	.219	.214	.195	.179	.146	.126
140		.280	.265	.244							
180			.214	.208							

TABLE 22A.

from Hausen's work.

P	−73.2° C.	−23.2° C.	+26.8° C.
1	.505	.36	.27
20	.53	.36	.27
60	.515	.345	.26
100	.425	.325	.25
140	.34		

TABLE 23.

μ and η COMPARISON WITH WORTHING.

	μ				η			
	W	R	W	R	W	R	W	R
P	−79.3° C.	−75° C.	0° C.	0° C.	−79.3° C.	−75° C.	0° C.	0° C.
1	.230	.462		.240		.448		.311
20	.464	.438	.226	.249	.476	.438	.259	.299
60	.424	.377	.212	.266	.474	.427	.278	.275
100	.293	.287	.186	.280	.368	.360	.270	.244
140	.214	.196	.130		.296	.280	.233	

TABLE 24.

Elastic Coefficient, $-\gamma = \frac{1}{v}\left(\frac{dv}{dp}\right)_t$ (atm.)$^{-1}$.

P	−100° C.	−75° C	−50° C.	−25° C.	0° C.	+25° C.	+50° C.	+75° C.	+100° C.	+150° C.	+200° C.	$1/p$
1	1.0051	1.0025	1.00179	1.00125	1.00014	1.00030	1.00014	1.00001	1.00018	0.99971	0.99944	1.0000
20	0.05534	0.05261	0.05151	0.05093	0.05050	0.05024	0.05004	0.04992	0.04982	0.04975	0.04965	0.05000
60		0.01878	0.01764	0.01730	0.01697	0.01680	0.01656	0.01645	0.01638	0.01632	0.01629	0.01667
100		0.01106	0.01123	0.01020	0.01011	0.00996	0.00982	0.00966	0.00961	0.00960	0.009575	0.01000
140		0.006797	0.006907	0.00734								0.007143
180			0.004853									0.005555

TABLE 25.

CORRECTIONS TO CONSTANT PRESSURE AIR SCALE TO BE ADDED TO EXPERIMENTAL DATA TO GIVE ° KELVIN.

	$p = 760$	$p = 1000$	$p = 1000$
$t°$ C.	Roebuck	Roebuck	Buckingham
+280	.202	.266	
250	.161	.212	
225	.127	.167	
200	.0959	.126	.105
175	.0668	.0879	
150	.0406	.0534	
125	.0181	.0238	
100	.0000	.0000	.0000
75	−.0128	−.0168	−.0151
50	−.0185	−.0243	−.0209
+25	−.0149	−.0196	−.0158
0	.0000	.0000	.0000
−25	.0289	.0380	
−50	.0971	.128	
−75	.154	.203	
−100	.273	.359	0.326
	Air	Air	Nitrogen

TABLE 26

$$\lambda = \left(\frac{du}{dv}\right)_t \text{ IN ATM.}$$

P	−100° C.	−75° C.	−50° C.	−25° C.	0° C.	+25° C.	+50° C.	+75° C.	+100° C.	+150° C.	+200° C.
1	.006182	.005681	.004194	.003351	.002779	.002381	.001919	.001597	.001078	.001066	.000795
20	3.072	2.474	1.838	1.404	1.120	.9339	.7239	.6505	.5449	.3878	.3078
60		26.11	18.41	12.77	9.985	7.936	6.894	5.778	4.879	3.524	2.651
100		84.53	45.02	36.99	26.05	21.09	17.71	15.79	13.42	9.456	7.181
140		173.4	102.8	64.57							
180			158.0								

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DIFFUSE MATTER IN INTERSTELLAR SPACE.

BY J. S. PLASKETT, F. R. S.

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By J. S. Plaskett, F. R. S.

(Read before the Academy, April 9, 1930).

Over twenty-five years ago, Hartmann first observed in the spectroscopic binary δ Orionis that the *H* and *K* lines of calcium did not share in the velocity oscillations, due to the binary motion, of the hydrogen and helium lines of the star, but remained relatively fixed in position. Hence the name "stationary" calcium lines which has served for their designation almost to the present time. Although many more examples of spectroscopic binaries which were always of early type, of very high temperature stars with stationary calcium lines were discovered in the following twenty years, it was believed that these lines were associated only with binaries and were due to the absorption of a surrounding cloud of ionized calcium attached to and moving with the binary system in its journey through space.

I was first led to suspect that this was not the true explanation when the investigation of the massive eclipsing system *Y* Cygni in 1920 showed that the constant velocity given by the "stationary" lines in this star differed by nearly 40 km. per second from the velocity of the centre of gravity of the revolving pair. In such a case of rapid relative motion the pair would soon escape from any limited surrounding cloud. This was only an isolated example but when it was shown about three years later in my investigation of the radial velocity of stars of type *O*, that a similar phenomenon was repeated in these stars, it seemed necessary to modify the early hypothesis. The stars of *O* type are the stars of highest temperature, greatest mass and highest luminosity in the sky and it was soon found that these "stationary" lines were present not only in spectroscopic binaries but in practically all stars of the class and that the velocity given by these lines generally differed, frequently markedly, from the velocity given by the lines of hydrogen, helium, etc. arising in the stellar atmosphere itself. These differences were sometimes so great, up to 50 and 60 km. per second, in comparison to the probable errors, of the order of one km. per second, of the velocities as to leave no reasonable doubt of the presence in space of gaseous matter containing ionized calcium through which these *O* type stars were rushing about in all directions.

The wide distribution of this gaseous material was more evident, and its independence of ordinary stellar matter and the spectral lines produced by this matter, was rendered more certain by the appearance of these "interstellar" lines, as we prefer to call them, in the spectra of the novae and of the Wolf Rayet stars in which no ordinary star lines appear. Further, when it was shown that this "interstellar" matter was nearly stationary with respect to the stellar system the conclusion was almost inevitable that it had a relatively extensive distribution, and that the stars were moving rapidly in all directions through it. As these "interstellar" calcium lines, differentiated from the other star lines by their extreme narrowness and sharpness, had not hitherto appeared in stars of type later than B3, in stars of the highest temperature only, it was assumed that the calcium in this diffuse matter was ionized and rendered absorbing at *H* and *K* by the excitation of neighboring high temperature *O* and *B* type stars.

This hypothesis, following closely Hubble's ideas of the excitation of the luminous gaseous nebulae by neighboring high temperature stars, was due mainly to the suggestion of my son, H. H. Plaskett, now professor of astrophysics at Harvard and required the assumption of a much wider distribution of this diffuse matter than was entailed by the earlier hypothesis of a surrounding cloud of material. Further, as the *D* lines of neutral sodium, of the same sharpness and stationary position as *H* and *K*, had also been found in these high temperature stars, there seemed good reason to believe that the interstellar matter was of the same composition as the stars and contained most of the elements present on the earth. The *D* lines and *H* and *K* are however the only lines likely to be present in the readily observable region of stellar spectra as the ultimate lines of other elements of sufficiently great abundance are mostly in the far ultra-violet. There finally resulted the hypothesis, advanced about 1923, that there was an extensive distribution of very diffuse matter practically stationary with respect to the stellar system extending to distances of several thousand light years, through which the stars were moving rapidly in all directions and which was rendered absorbing to the *D* lines and to *H* and *K* by the excitation of the stars of highest temperature.

I have been led to believe that the results of this investigation, demonstrating the rapid motions of the hottest and most distant stars in the sky in all directions through relatively stationary diffuse matter in interstellar space formed the starting point for Eddington's masterly exposition of the physical conditions of this diffuse matter as given in the 1926 Bakerian Lecture of the Royal Society. If so, it is a striking instance of a deduction of great cosmic importance following closely upon accurate observational data obtained for an entirely different purpose. I am proud of having provided the observational material and given a preliminary hypothesis on which this important contribution of Eddington's may have been based and would like to believe that other work of ours may prove equally useful. While it is natural for an astronomer to wish to discuss as fully as possible his own observations, I think he should realize, particularly if he is fortunate enough to have the observational opportunities of a 72-inch telescope, that it will be generally more useful to science if he devotes his energies mainly to making accurate observations. In this particular case, however, as will be seen in the sequel, we were fortunate enough not only to provide the starting point of a great contribution, but to furnish recently the additional data which rounded off and gave the final finishing touch to Eddington's theory.

In his Bakerian Lecture, Eddington discussed theoretically the physical condition present in interstellar space and, on the *assumption* that the diffuse matter was uniformly distributed except where local condensations formed the diffuse nebulae, showed that the density of this matter could not be greater than about 10^{-24} gm/cm^3. Otherwise the gravitational force due to the combined mass of this diffuse matter and of the stars would give velocities to the latter considerably greater than observed. Some three years later Gerasimovic and Struve from calculations based on the intensity of the "interstellar" line K gave a density of about 10^{-26} gm/cm^3 only one hundredth of Eddington's admittedly maximum value. It will probably be of interest, before proceeding to give some idea in more familiar terms of what a density of 10^{-25} gm/cm^3, the mean of the two estimates, actually means. Obviously it implies that one gram of this diffuse matter will be distributed through a volume of space 10^{25} c.cm., a cube with sides 2×10^8 cm., or about 1400 miles. Or in the whole volume of the earth, there would only be about 4 ounces of this material. In the face of this almost inconceivable tenuity the highest terrestrial vacuum is crowded with molecules.

Eddington's calculations of the temperature were equally interesting although almost paradoxical in character. The temperature of such diffuse gaseous matter calculated as of the order of 10,000° or 12,000° C., is defined as the speed of the molecules given by such a temperature and not as the temperature, some 270° C. below zero that a black body in outer space would assume. This molecular speed or temperature is due to and was calculated from the radiation from all the stars and is so high that most of the calcium present will be doubly ionized and the sodium singly ionized, these two elements being the only ones likely to give lines of sufficient intensity in the observable region of stellar spectra. Both of these ionized atoms however give their fundamental lines only in the far ultra violet, where they cannot be observed. However, about one part in 3000 of the calcium atoms would be singly ionized and thus capable of absorbing star light at *H* and *K* but only one part in 2,000,000 of the sodium atoms would remain neutral. Eddington calculated at the density of 10^{-24} gm/cm^3 that there should be sufficient absorption to show the *H* and *K* lines in stars at a distance of about 100 parsecs, 325 light years. There now seems good reason to believe that these interstellar lines do not become plainly visible in stars nearer than two or three times that distance, an indication of a lower density of the diffuse matter. Similarly, according to theory there will be so small a fraction of neutral sodium left that the *D* lines should never be visible, whereas observation shows they are of practically the same intensity as *H* and *K*. So much the worse then for the theory in which some unknown factor must enter. Gerasimovič and Struve calculate the effective temperature as nearer 15,000° which makes the presence of the *D* lines all the more mysterious.

We may now with advantage summarize briefly what has been learned about this very diffuse matter in interstellar space. The investigation of the *O* type stars had shown that this matter was widely distributed through the stellar system and that the high temperature stars were moving rapidly through it in all directions. It was further shown that after the removal of the solar motion, the residual velocities were relatively small and that this diffuse matter, which was later assumed to be uniformly distributed throughout the stellar system was nearly at rest with respect to this system. Eddington had calculated in a beautifully complete way its physical properties and it appears that the density is of the order of 10^{-25} gm/cm^3, four ounces in the volume of the earth, and that the temperature as represented by the molecular speed is from 10,000° to 15,000° C. As a consequence of the assumption of uniform distribution, the greater the distance of the star, the greater the depth of absorbing matter and the stronger will be the *H* and *K* lines. The *D* lines will behave similarly, but, owing to the greater difficulty of observing the latter, the data are practically confined to *H* and *K*.

Struve early recognized that, if this interstellar matter were uniformly distributed, the strength of *H* and *K* should increase with the distance of the star. His examination of slit spectrograms of *O* and *B* type stars at Yerkes, Victoria, Lick and Mt. Wilson observatories gave somewhat conflicting results but a second attempt from the great wealth of Harvard objective prism spectra showed a gradual increase of intensity of the *K* line as the stars became fainter and hence presumably more distant. There was, however, owing to heterogeneity of the material some uncertainty about his conclusions, and a later investigation by Gerasimovič and Struve on the motions of this interstellar matter, a considerable part of their observational material consisting of published Victoria results was of a qualitative rather than a quantitative character. I think it is preferable therefore to give here the results of the observational work at Victoria, purposely withheld until the data were complete and definite quantitative results were available.

The earlier Victoria results proved that the high temperature stars were moving in all directions through diffuse gaseous matter, shown to be approximately at rest with respect to the stellar system. Eddington then calculated, in his masterly Bakerian lecture, the physical conditions of this interstellar material on the assumption that it was uniformly distributed throughout the stellar system. The recent Victoria results by my colleague, J. A. Pearce, and myself have not only definitely established the uniform distribution of the diffuse matter but shown that it is not exactly at rest as earlier supposed but partakes in a beautifully exact way of the differential motions produced by the rotation of the galactic system.

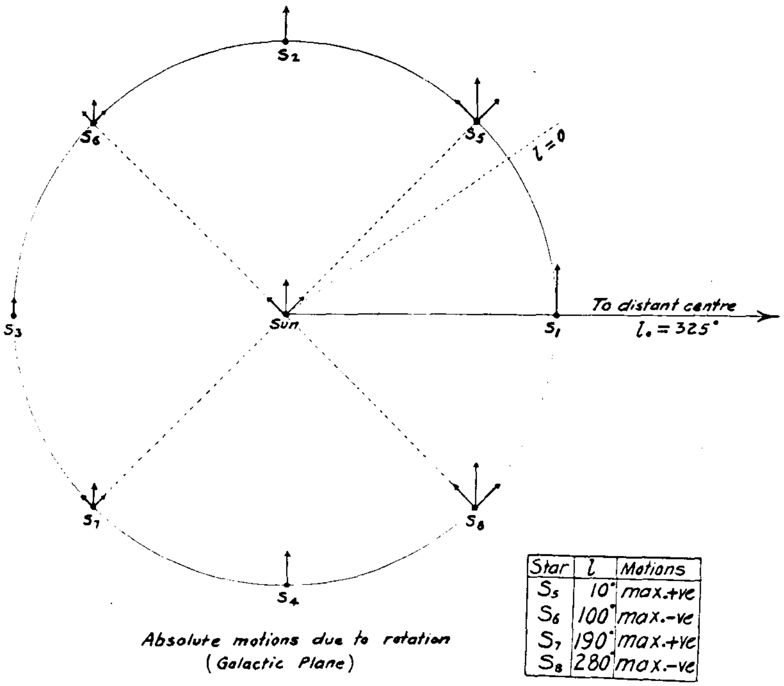
The observational material on which these final results are based has been gradually accumulating at Victoria for nearly ten years, first in my own work on the radial velocities of the *O* type stars and since 1924 in our joint investigation of the radial velocities of all *B*0 to *B*5 stars brighter than 7.5 visual magnitude and north of declination −11° whose velocities had not been previously determined. Altogether over 500 *O* to *B*5 stars were critically examined for the presence of "interstellar" *H* and *K* and a catalogue compiled. This catalogue contained over 260 stars, all but about a dozen of which were obtained at Victoria, and in which the radial velocities of the interstellar matter between us and the corresponding stars were determined. For about a dozen, such as the Novae and Wolf Rayet stars, no stellar velocity can be obtained while in about 20 others with reliable interstellar velocities, the stellar velocity was uncertain. Hence there were for the discussion 230 stars in which not only the radial velocity of the star itself but the velocity of the diffuse matter between us and the star was known and for which an estimate of the intensity of the "interstellar" *H* and *K* lines was available.

It will be remembered that the early work on the *O* type stars had shown that the radial velocities of the intervening diffuse matter, after the removal of the component of the standard solar motion of 20 km. per sec. towards $\alpha = 271°$, $\delta = +28°$, the residual velocities, as they are called, were relatively small, as if the diffuse matter was practically at rest with respect to the stellar system, with the stars moving through it in all directions. The final analysis of all the 260 residual motions shows however that the interstellar matter is not exactly at rest but partakes, along with the stars, in an orderly and majestic rotation of the galactic system. I think I may safely assume that everyone in my audience has heard something about the galactic rotation based on the work of Lindblad and Oort and most convincingly demonstrated from the motions of the *O* and *B* type stars obtained at Victoria. Possibly, however, a short description of the essentials of the rotational idea may be useful.

It would seem at first sight an impossible task to determine, from our position within the stellar system, where all the stars we can observe are rotating as well as ourselves, and when the galaxy can not be observed from without, whether any such rotation exists. If the stars and other matter throughout the system are uniformly distributed, elementary dynamics at once indicates that all the stars will revolve with the same angular velocity or the system will rotate like a solid disc or wheel. In such a case there will be no relative motion between the sun and neighboring stars and no rotation could be detected, just as a fly on the spoke of a rapidly rotating wheel could not tell from observing other flies on the hub or rim whether the wheel was stationary or spinning. Fortunately, however, we have good reason to believe that instead of uniform distribution, the stars are more condensed towards the centre of the system. The conditions of rotation will then approximate those in the solar system where most of the matter is at the centre and where the inner planets rotate more rapidly, both linearly and angularly, than the outer. If the galaxy rotates in this manner, there will obviously be relative motion between the sun and neighboring stars which can be measured by the spectroscope and the circumstances of the rotation determined.

Oort developed the simple relation that exists between the radial velocities of neighboring stars and showed that the rotational effect is directly proportional to the distance from the sun and varies as we go around the galaxy, with the sine of twice the angle between the star and the direction of the gravitational centre. This centre is

ROTATION OF THE GALAXY



Star	l	Motions
S_5	10°	max.+ve
S_6	100°	max.-ve
S_7	190°	max.+ve
S_8	280°	max.-ve

Absolute motions due to rotation
(Galactic Plane)

generally assumed as in galactic longitude 327° and as coinciding with the centre of the system of globular clusters. The rotational effect $\bar{r}A$ is composed of the constant dynamical term A of an average value as determined by Oort and Plaskett of 1 km. per sec. for stars 60 parsecs, 200 light years from the sun. This value of A obviously provides a new method of obtaining the average distance $\bar{r}$ of a group of stars from the sun when $\bar{r}A$ has been obtained and also gives accurate relative distances, independent of the value of A, of groups of stars or interstellar matter. I should like you to remember this deduction of the galactic rotation as it has an important application later. The diagram shows graphically how the rotational swing of the velocities has a double wave effect as one goes around the galaxy.

The radial velocities of the interstellar matter in the directions of some 260 stars were first analysed for the solar motion and the galactic rotation simultaneously by the method of least squares which is nothing more than a mathematical device for obtaining the most probable values of these unknown quantities from all the data. The results of this analysis and the equations used are shown in Table I

TABLE I.—SOLUTIONS OF INTERSTELLAR MOTIONS.

$$\bar{V} = X \cos L \cos B + Y \sin L \cos B + Z \sin B + \bar{r}A \sin 2(\bar{l} - l_0) \cos^2 \bar{b} + K$$

where

$\bar{V}$ = Average Radial Velocity of Group of Stars
X, Y, Z = Three Components of Solar Velocity
L = Galactic Longitude Solar Apex
B = Galactic Latitude Solar Apex
$\bar{r}$ = Average Distance of Group of Stars
A = Radial Rotational Term
$\bar{l}$ = Galactic Longitude of Group of Stars
$\bar{b}$ = Galactic Latitude of Group of Stars
lo = Galactic Longitude of Centre of Rotation
K = Average Residual Velocity

	1. General Solution	2. Particular Solution	
$V =$	$+$ 19.90 ± 2.40 km. per second	$+$ 20.00	Assumed
$L =$	25°.9 ± 11°.8	21°.8	
$B =$	$+$ 3°.6 ± 11°.8	$+$ 20°.0	
$\bar{r}A =$	$+$ 7.30 ± 1.98	$+$ 7.90 ± 0.79	
$K =$	$+$ 0.55 ± 2.70	$-$ 0.61 ± 0.57	
$=$	335°.1 ± 15°.5	331°.7 ± 5°.7	

and it is at once seen that the solar velocity agrees exactly with that obtained from the naked eye stars, of 20 km. per sec. This is interesting and important as indicating the normal motion of the interstellar matter. The position of the solar apex is however, about 20° distant from the normal position, not surprising in view of the unsuitable distribution so closely confined to the galactic plane. The rotational term of + 7.3 km. corresponds to an average distance of the centres of absorption of the diffuse matter of about 1450 light years. A second solution was made for galactic rotation only, first removing the component of the standard solar motion. The results are much more accurate and give an average distance of nearly 1600 light years and a direction to the centre of 331°.7 ± 5°.7 agreeing with the accepted position well within the probable errors of the determination. I think all will agree when the observed and computed velocities, $\bar{v}$ and v' for the first or general solution and $\bar{\rho}$ and ρ' for the second solution for galactic rotation only, Table II, are compared that this diffuse matter follows remarkably closely the double wave swing of the velocities produced by a rotation of the galaxy. The early assumption that this interstellar matter is relatively at rest was evidently erroneous as the residual velocities $\bar{\rho}$ are of considerable magnitude and are practically removed by the rotational effect, as the residuals remaining, $\bar{\rho} - \rho'$, are negligible except in two or three positions which time does not permit us to discuss. There can be no reasonable doubt that this interstellar diffuse matter, indeed almost

TABLE II.—COMPARISON OF OBSERVED AND COMPUTED VELOCITIES.

				1. General Solution			2. Particular Solution		
No.	*	$\bar{l}$	$\bar{b}$	$\bar{v}$	v'	$\bar{v} - v'$	$\bar{\rho}$	ρ'	$\bar{\rho} - \rho'$
1	4	346°	+22°	−12.7	−11.7	− 1.0	+ 3.4	+2.6	+ 0.8
2	4	353	− 7	−12.2	−11.7	− 0.5	+ 3.9	+4.6	− 0.7
3	15	19	+ 5	−13.4	−12.0	− 1.4	+ 5.8	+7.2	− 1.4
4	8	32	+ 5	−13.1	−12.6	− 0.5	+ 5.7	+6.2	− 0.5
5	4	38	−32	− 6.4	−11.0	+ 4.6	+ 5.0	−3.5	+ 1.5
6	32	41	+ 1	−13.6	−13.2	− 0.4	+ 4.2	+4.5	− 0.3
7	20	52	+ 1	−10.8	−14.1	+ 3.3	+ 5.0	+2.1	+ 2.9
8	33	71	+ 6	−15.0	−15.0	− 0.0	− 2.3	−3.1	+ 0.8
9	17	67	−13	−14.5	−14.2	− 0.3	− 3.2	−1.9	− 1.3
10	18	86	− 5	−14.4	−14.0	− 0.4	− 6.9	−6.4	− 0.5
11	7	96	− 3	−14.8	−12.6	− 2.2	−10.5	−7.9	− 2.6
12	11	104	− 1	−21.4	−10.6	−10.8	−18.9	−8.5	−10.4
13	15	116	+ 2	− 3.5	− 6.8	+ 3.3	− 4.4	−8.1	+ 3.7
14	13	132	− 5	+ 8.5	+ 0.8	+ 7.7	+ 1.0	−5.7	+ 6.7
15	14	156	− 2	+12.0	+12.4	− 0.4	− 0.5	−0.1	− 0.4
16	16	172	+ 3	+19.0	+20.9	− 1.9	+ 3.2	+4.5	− 1.3
17	24	173	−17	+19.3	+20.3	− 1.0	+ 2.2	+4.5	− 2.0
18	4	194	0	+31.3	+27.1	+ 4.2	+12.8	+7.2	+ 5.6
19	2	218	+54	+13.4	+12.4	+ 1.0	+ 8.4	+1.4	+ 7.0

its individual molecules, partakes almost exactly of the orderly differential rotation of the galactic system.

This demonstration of the rotational motions of the interstellar matter leaves only the question of its distribution unsettled. This follows directly from the proportionality of the average distance of a group of stars or clouds to the rotational term $\bar{r}A$. As mentioned above there are available about 230 high temperature stars for which we have the radial velocities not only of the stars themselves but also of the intervening diffuse matter. The estimation of the intensity of "interstellar" *H* and *K* in these stars gives, as was indicated above, a means of arranging them in groups according to distance. A second method of grouping in distance which, however, owing to the dispersion in the intrinsic brightness of the stars is not so critical, is by arranging them in groups in apparent magnitude. The arrangement by both methods is shown in Table III with the values of the rotational term, $\bar{r}A$, for both stars and intervening matter for each group. Except for the brighter and nearer stars, where the rotational term is indeterminate, the remarkable relation holds almost exactly that $\bar{r}A$ for the stars is just twice that for the corresponding intervening diffuse matter, in other words that the average distance of each group of stars is just twice that of the centre of gravity of the intervening clouds. When this holds for the seven more distant groups at average distances from the sun of 2,000, 3,000, 4,000 and 5,500 light years

TABLE III.—SOLUTIONS OF MAGNITUDE GROUP.

			rA	
Group	No.	*m*	Stars	Clouds
1	37	4.41	+ 1.81±2.8	+ 3.85±1.2
2	45	5.60	+10.26±2.1	+ 5.02±1.2
3	79	6.03	+13.86±1.8	+ 7.66±0.9
4	119	7.00	+16.58±2.2	+ 8.31±1.4
5	69	7.34	+20.49±2.3	+10.08±1.6

SOLUTIONS OF INTENSITY GROUPS.

			rA	
Group	No.	*I*	Stars	Clouds
1	42	4.72	+ 3.64±3.2	+ 4.97±0.8
2	662	6.50	+12.12±1.9	+ 4.93±0.9
3	90	6.08	+10.22±1.7	+ 5.03±0.8
4	79	7.46	+14.53±2.9	+ 6.91±1.1
5	43	8.42	+27.52±2.5	+13.72±1.2

TABLE IV.—COMPARISON OF VELOCITIES.

Intensity of Interstellar Lines 4.4 to 6.9			$rA = +10.22$		$rA = +5.03$	
Group	No.	Mean Long.	Stellar Velocities		Cloud Velocities	
			Observed	Computed	Observed	Computed
1	2	345°	+36.2	+10.8	−1.2	+3.3
2	2	17	+ 5.9	+14.0	+4.9	+4.9
3	14	38	+10.4	+ 9.9	+5.7	+2.9
4	11	61	+ 6.4	+ 2.1	−0.4	−1.0
5	13	75	− 7.3	− 2.4	−0.4	−3.2
6	8	89	− 6.8	− 5.3	−6.0	−4.6
7	8	113	− 2.1	− 5.0	−6.9	−4.4
8	6	131	+ 4.5	− 0.5	+2.7	−2.2
9	8	156	+ 7.0	+ 8.0	−1.7	+2.0
10	13	174	+14.4	+12.6	+4.9	+4.1
11	3	205	− 2.6	+ 9.8	+3.4	+4.2
Intensity of Interstellar Lines 7.0 to 7.9			$rA = +14.53$		$rA = +6.91$	
1	8	12	+ 5.5	+14.3	+ 4.6	+ 6.7
2	12	38	+ 8.9	+ 8.0	+ 6.3	+ 3.7
3	11	51	+ 7.2	+ 1.7	+ 4.8	+ 0.6
4	10	65	− 1.5	− 5.3	− 0.9	− 2.6
5	4	75	− 7.8	− 9.5	− 2.4	− 4.7
6	8	89	−20.2	−13.7	−10.6	−16.7
7	3	110	−23.9	−13.9	− 9.7	− 6.7
8	3	139	+ 1.7	− 3.2	− 0.3	− 1.7
9	9	160	+10.6	+ 7.2	+ 0.2	+ 3.3
10	10	174	+17.2	+12.2	+ 2.7	+ 5.6
11	1	192	+44.6	+14.4	+13.0	+ 6.7
Intensity of Interstellar Lines 8.0 to 9.5			$rA = +27.52$		$rA = +13.72$	
1	2	358	+35.7	+24.3	+ 8.2	+ 9.4
2	2	17	+12.2	+29.3	+ 6.1	+11.9
3	6	34	+21.5	+21.3	+ 7.5	+ 7.9
4	2	47	+11.8	+10.4	+ 6.6	+ 2.4
5	12	70	− 3.4	−10.4	− 5.4	− 8.0
6	4	97	−26.8	−23.4	−15.5	−14.3
7	9	107	−28.4	−23.5	−17.7	−14.5
8	4	141	− 4.1	− 0.9	+ 1.2	− 3.2
9	2	169	+13.6	+16.0	+ 1.9	+ 5.3

and intermediate distances there can be no escape from the conclusion that this very diffuse interstellar matter is uniformly distributed throughout the space inhabited by the *O* and *B* type stars, to distances of at least 5,500 light years from the sun. It will be worth while to show a comparison of observed and computed residual velocities, Table IV, to give further ocular demonstration of the unmistakable reality of the galactic rotation.

The conclusions in regard to the presence, properties and motions of diffuse matter in interstellar space may be profitably summarized in three stages:—

1. The early investigation of the radial velocities of the *O* type stars at Victoria conclusively showed the fairly extensive distribution of diffuse interstellar matter which at first appeared to be nearly at rest in the stellar system and through which the high temperature stars were rapidly moving in all directions.

2. Eddington, on the basis of this observational data, developed a beautiful theory of the physical properties of this diffuse matter whose density, temperature and the conditions for the selective absorption of the star light were calculated. These calculations entailed the assumption of uniform distribution of the interstellar material.

3. Just as the early observations at Victoria furnished the foundation on which Eddington built his masterly theoretical super-structure, so our more recent investigation may rightly claim to have placed the final observational capstone on the whole structure. It seems to me it has added immeasurably to our conviction of the objective reality of this exceedingly diffuse interstellar matter to have proved that it partakes in the most beautifully exact way of the differential motions produced by a rotation of the galaxy and to have demonstrated conclusively from these motions that it is uniformly distributed throughout the stellar system.

The history of the manner in which the presence and properties of diffuse matter in interstellar space were discovered, calculated and demonstrated forms a striking illustration of the fruitful combination of theory and practice.

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A PHOTOGRAPHIC INVESTIGATION OF TWENTY-FIVE SOUTHERN CEPHEID VARIABLE STARS.

By Harlow Shapley.

A PHOTOGRAPHIC INVESTIGATION OF TWENTY-FIVE SOUTHERN CEPHEID VARIABLE STARS.

By Harlow Shapley.

(Read by title May 14, 1930.)

As a detail in the study of the structure of the galactic system, the distribution of the Cepheid variables is of much significance. When associated with the remote star clouds, they afford at present the best means of estimating distances and dimensions; and those Cepheid variables that are not members of star clouds or globular clusters may help to indicate by their space distribution the location and extent of obscuring nebulosity.

The study of the very faint variable stars of the Milky Way requires the accumulation of special series of long exposure photographs. Such investigations are now in progress at the Harvard Observatory for a large number of fields, with emphasis on the star clouds in the general direction of the galactic center. The brighter isolated Cepheids can be satisfactorily studied by means of the plates of the sky patrol. Several hundred observations can be derived from existing plates for all those brighter than the twelfth magnitude, without the necessity of special series of photographs. The observations are well distributed throughout some thirty years. The plates therefore permit the satisfactory investigation of changes in period and light curve, and contribute to the general study of Cepheid variability.

The present investigation of Cepheid variable stars has been made possible through a grant by the American Academy of Arts and Sciences from the income of the Permanent Science Fund of the Boston Safe Deposit and Trust Company. Practically all the observations have been made by Mrs. Robinson, and Mr. Robinson has assisted in certain details of comparison star sequences and the reduction of the observations.

I have considered only those variable stars that lie in a region of the southern Milky Way which has already been chosen for detailed investigation.[1] In this region of the galactic center, covering some seventy square degrees, a study of the distribution of variable stars of all kinds, of bright and dark diffused nebulosity, of external galaxies, of star clouds, and of other special objects is under way. Nearly all the Cepheid variable stars of this region that appear in Prager's catalogue have been observed for the present study, except the very faint variables in the special Milky Way fields that are in the programs of various observers at Harvard and Nantucket. Twenty-eight stars have been measured, of which one was found to be an eclipsing system of the β Lyrae type and two apparently irregular variables. On the Cepheids 7883 observations have been made. Here I shall chiefly present observational results; their bearing on galactic structure and Cepheid variability will be discussed elsewhere.

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[1] Harvard Reprint, 52, 1928.

General information concerning the twenty-five Cepheids is given in Table I. The contents of the first four columns are obvious. The ratio of the duration of increasing light to the length of the period is given in the fifth column. Only one-sixth of these variables have a ratio greater than 0.4 — the curves are nearly all decidedly asymmetrical. The mean maximum magnitude, minimum magnitude, and range are in columns six to eight; the range in spectral class as shown on Harvard plates is given in the ninth column, and the computed distance from the Sun, in parsecs, based on the new period-luminosity curve,[1] is given in the last column.

Revised elements of the light variations are given for all twenty-five variable stars in Table II. For the periods of less than one day (RW TrA, S Ara) the times have been reduced to the Sun. The probable errors of the epochs of maximum and of the periods have been obtained from least squares solutions. The last column of the table contains the difference between revised periods and those given in Prager's catalogue for 1930, in the sense Harvard — Prager. It appears that many of the corrections are large and that only two are smaller than the probable error of the corrected periods.

The comparison star sequences are given in Table III. The spectral classes in the last column were taken from the Henry Draper Catalogue when possible; otherwise the classifications have been made by Miss Cannon especially for this tabulation. Accuracy in the magnitudes of the photographic sequences is not claimed. The standard sequences in the southern sky, which were used as the basis for the special comparison star sequences of Table III, are still rather provisional. A scale error of greater than ten per cent is not likely, but the zero point of the magnitude sequences may be in error by two or three tenths of a magnitude and correspondingly affect the distances given in the last column of Table I.

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[1] Harvard Observatory Monograph No. 2, 1930.

The individual observations of the twenty-five Cepheid variable stars are given concisely in Table IV. The first column contains the Julian Day (with the first two numbers, 24, omitted for all observations), the decimal of a day, and a letter indicating with which telescope the photograph was made. The indications are as follows: e, AC (1-inch Cooke, Cambridge); f, AM (1-inch Cooke, Arequipa); q, AI (½-inch Voigtlander, Cambridge); r, RH (3-inch Ross, Cambridge); y, AY (2-inch Zeiss Tessar, Cambridge); z, AX (2-inch Ross-Zeiss Tessar, Arequipa and Bloemfontein). The phases have been computed with the revised elements. The photographic magnitudes are single estimates, except in a few cases of duplicate observations, where the means are tabulated.

Normal points for the variables are contained in Table V. The mean phases are in fractions of the whole period and are referred to a zero point half-way between maxima. Each mean contains in general twenty observations formed by taking the mean of successive groups of ten observations. The third decimal place in magnitude is computational only. The number of normal points for a given star depends on the number of observations.

For BF Ophiuchi, X Sagittarii, W Sagittarii, BB Sagittarii, and κ Pavonis three or four times the average number of observations were made in order to test for irregularities of period or light curve. In making the observations on the other Cepheid variables only a part of the total available material was used, but the plates were so selected as to cover the whole interval of thirty years that has elapsed since the sky patrol on small scale plates was inaugurated.

Mean light curves of the variables have been plotted from the coordinates in Table V and are reproduced in the accompanying figures. For stars which were extensively observed separate mean light curves are given for short intervals of time. For X and W Sagittarii the scattering of the observations indicates the difficulty of the estimates. The changes in form of the light curves can be judged best from the figures. It should be remembered that for these bright variables the average accuracy of estimating magnitudes is considerably less than for stars between the seventh and twelfth magnitudes.

The amplitude of variation, eighth column of Table I, varies from 0.66 for S Normae to 2.34 for WZ Sagittarii. These exceptional cases suggest the possibility of erroneous magnitude scales; but a restudy of the comparison star sequences seems to give little ground for correction. Also, an examination of the scattering of the observations shows no appreciably greater error for the stars of large range than for those of small range, thus indicating with certainty that magnitude scales are not responsible for the large differences in amplitude. We should abandon the formerly common statement that ranges of Cepheid variables are practically all alike—one magnitude visual and twenty per cent more photographic.

Summary. Nearly eight thousand photographic observations have been made on twenty-five Cepheid variable stars situated in the southern Milky Way.

The average deviation of the photographic observations from the mean curve is approximately seven hundredths of a magnitude, indicating a very satisfactory accuracy.

For all the twenty-five Cepheids new formulae for maximum and period have been derived; new comparison star sequences have been set up, the amplitude of variation and the median magnitude determined, the distances computed, and the ranges in spectrum found from Harvard plates. The distances vary from two hundred forty parsecs to over five thousand; when the distance of the fainter Milky Way Cepheid variables becomes available the parallaxes here found will be of service in detailing the structure of the Milky Way in the direction of the galactic center.

The light curves derived for these variables show in general the dependence of form on period length, noted and studied by Hertzsprung. The discrepancies will be considered in a forthcoming study of the photographic light curves of more than a hundred of the bright galactic Cepheid variables.

May 14, 1930.

TABLE I. TWENTY-FIVE CEPHEID VARIABLES.

Variable Star	R.A. 1900			Dec. 1900		Galactic Coordinates		Number of Observations	$\frac{M-m}{P}$	Max.	Min.	Range	Spectrum	Distance in Parsecs
	h	m	s	°	′	°	°			m	m	m		
V Centauri	14	25	23	−56	26.7	284,	+3	198	0.26	6.96	7.99	1.03	F5–G7	600
R Trianguli Australis	15	10	49	−66	07.7	285,	−9	196	0.39	7.07	8.18	1.11	F5–G5	560
U Normae	15	34	37	−54	59.3	293,	−1	200	0.43	9.91	11.27	1.36	G0–K5	3400
S Trianguli Australis	15	52	12	−63	29.5	290,	−9	203	0.30	6.44	7.83	1.39	F5–K0	540
U Trianguli Australis	15	58	25	−62	38.3	291,	−9	210	0.25	7.96	8.84	0.88	F2–G5	740
S Normae	16	10	34	−57	39.2	296,	−6	207	0.48	7.19	7.85	0.66	F8–G2	750
RW Trianguli Australis	16	50	45	−66	31.0	291,	−16	240	0.23	10.79	11.70	0.91	A7	1760
RV Scorpii	16	51	47	−33	27.2	319,	+4	207	0.32	7.03	8.13	1.10	F5–G5	650
BF Ophiuchi	16	59	54	−26	26.6	325,	+7	838	0.34	7.69	8.47	0.78	F8–K2	730
X Sagittarii	17	41	16	−27	47.5	329,	−1	923	0.34	4.84	5.89	1.05	F5–G9	240
RY Scorpii	17	44	16	−33	40.5	324,	−4	209	0.36	8.32	9.62	1.30	F8–K0	1940
S Arae	17	51	27	−49	25.2	311,	−13	232	0.17	9.97	11.10	1.13	A3–F5:	1300
W Sagittarii	17	58	38	−29	35.1	330,	−5	945	0.32	4.73	6.15	1.42	F2–G6	260
AP Sagittarii	18	06	58	−23	08.5	336,	−4	206	0.30	7.51	8.31	0.80	F5–K0	720
WZ Sagittarii	18	11	07	−19	06.6	340,	−3	209	0.33	8.12	10.46	2.34	G0–K5	2330
XX Sagittarii	18	18	57	−16	51.0	343,	−4	198	0.30	9.27	10.90	1.63	F8–K0	2100
X Scuti	18	25	42	−13	10.7	346,	−3	199	0.26	10.67	11.81	1.14	F5–K2	3150
U Sagittarii	18	26	00	−19	11.7	341	−6	203	0.33	7.96	9.11	1.15	F8–K0	1030
Y Scuti	18	32	36	− 8	27.3	351,	−3	183	0.39	10.69	11.72	1.03	G2–K7	4200
RU Scuti	18	36	40	− 4	12.4	356,	−1	199	0.24	10.41	11.81	1.40	G5–M	5200
Z Scuti	18	37	36	− 5	55.1	355,	−2	196	0.40	10.15	11.97	1.82	G0–M0	4300
SS Scuti	18	38	18	− 7	49.8	353,	−3	194	0.40	8.70	9.92	1.22	F8–G5	1250
YZ Sagittarii	18	43	42	−16	50.1	345,	−9	200	0.49	8.08	8.80	0.72	G2–K2	1100
BB Sagittarii	18	45	04	−20	24.6	342,	−10	615	0.35	7.60	8.61	1.01	F8–K0	860
κ Pavonis	18	46	38	−67	21.5	295,	−26	473	0.44	4.73	5.50	0.77	F5–G5	240

TABLE II.

Revised Elements for Twenty-five Cepheid Variables

Star	Elements and Probable Errors	ΔP
V Centauri	J. D. 2419068.927 + $5^{d}.494043$E ±0.028 ± 0.000056	$-0^{d}.000057$
R Trianguli Australis	20224.577 + 3.389287E ±0.017 ± 0.000021	+0.000017
U Normae	20022.134 + 12.642665E ±0.028 ± 0.000194	+0.001665
S Trianguli Australis	19816.303 + 6.323557E ±0.016 ± 0.000044	+0.000457
U Trianguli Australis	19722.277 + 2.568339E ±0.013 ± 0.000014	+0.000039
S Normae	20911.024 + 9.752960E ±0.339 ± 0.001639	−0.006840
RW Trianguli Australis	18149.3341 + 0.37403507E* ±0.0012 ± 0.00000013	....
RV Scorpii	20499.353 + 6.061428E ±0.016 ± 0.000036	−0.000772
BF Ophiuchi	20418.868 + 4.068012E ±0.009 ± 0.000013	+0.000112
X Sagittarii	19213.060 + 7.011154E ±0.016 ± 0.000048	+0.002054
RY Scorpii	19664.594 + 20.314133E ±0.122 ± 0.001038	+0.001733
S Arae	20047.2382 + 0.451888176E† ±0.0017 ± 0.000000262	....
W Sagittarii	20293.773 + 7.594973E ±0.014 ± 0.000044	−0.001827

TABLE II.—*Cont.*

Star	Elements and Probable Errors			ΔP
AP Sagittarii	J. D. 2419491.158	+	5.058132E	+0.000132
	±0.020	±	0.000047	
WZ Sagittarii	20889.050	+	21.847498E	−0.002402
	±0.028	±	0.000217	
XX Sagittarii	19189.730	+	6.424264E	+0.000244
	±0.014	±	0.000042	
X Scuti	20934.435	+	4.198026E	+0.000766
	±0.017	±	0.000024	
U Sagittarii	20600.325	+	6.744917E	−0.001383
	±0.017	±	0.000043	
Y Scuti	20138.056	+	10.341392E	−0.005608
	±0.024	±	0.000088	
RU Scuti	19198.251	+	19.696466E	−0.005534
	±0.030	±	0.000221	
Z Scuti	20133.222	+	12.901723E	+0.002723
	±0.040	±	0.000180	
SS Scuti	19984.342	+	3.6711843E	−0.0088157
	±0.014	±	0.0000018	
YZ Sagittarii	19741.300	+	9.553151E	−0.000079
	±0.024	±	0.000086	
BB Sagittarii	19282.142	+	6.636794E	−0.1238
	±0.017	±	0.000048	
κ Pavonis	19619.07	+	9.08979E	−0.00116
	±0.22	±	0.00089	

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* The period of RW TrA in Prager is $0^{\mathrm{d}}.699$.

† Additional term of formula for S Arae is $-0^{\mathrm{d}}.000000000095E^2$
$\pm 0.000000000038E^2$

NOTES ON INDIVIDUAL STARS.

S Normae, which is located in a loose cluster, has a faint companion star which interferes with accurate magnitude work as well as with the determination of the spectrum.

BF Ophiuchi has been treated in detail on the basis of our new measures in Harvard Bulletin 875, 1930. The normal points and light curves are not reproduced in the present communication.

RY Scorpii has a faint companion star which is not evident on the small scale plates that were used for the magnitudes. Apparently it influences the range at minimum magnitude very little.

X Sagittarii, W Sagittarii, and κ Pavonis, all being bright variables, were observed without an eyepiece on plates of the AC and AM series; for such bright variables the comparison stars are widely scattered.

S Arae was observed on only two spectrum plates, and the one giving Class F5 is very poor.

U Sagittarii is situated in a loose cluster and the magnitude estimates were accordingly difficult.

SS Scuti has been observed on sixty eight Nantucket plates in addition to the photographs of the Harvard collection. I am indebted to Miss Harwood for permission to use the Nantucket series.

BB Sagittarii has a bright companion of magnitude 7.74. On approximately one-third of the plates examined the images of the two stars were in contact.

TABLE III

Comparison Star Sequences

Star	H.D.	R. A. 1900		Dec. 1900		Adopted Pg. Mag.	Spectrum
V Centauri							
		h	m	°	′	m	
a	127486	14	26.5	−54	34	6.46	F5
b	126692	14	21.9	−55	41	7.22	A5
c	126876	14	23.0	−56	28	8.09	B8
R Trianguli Australis							
a	133683	15	0.6	−66	42	6.85	F8p
b	135139	15	8.4	−65	44	7.11	B9
c	136093	15	13.6	−65	51	7.48	A0
d	134709	15	6.2	−65	47	8.34	A0
U Normae							
a	139682	15	34.4	−54	34	9.21	A0
b	140058	15	36.5	−55	8	9.99	A5
c	....	15	36.2	−55	3	10.48	F2
d	....	15	35.3	−54	58	11.03	A7
e	....	15	36.0	−55	9	11.36	K5
S Trianguli Australis							
a	142514	15	49.8	−64	45	5.37	B8
b	144231	15	59.6	−62	42	6.80	B9
c	143832	15	57.5	−63	4	7.61	A0
d	143289	15	54.4	−63	5	8.35	F8
U Trianguli Australis							
a	143832	15	57.5	−63	4	7.61	A0
b	143289	15	54.4	−63	5	8.35	F8
c	143221	15	54.0	−62	50	8.89	K5
d	143039	15	52.9	−62	44	9.55	A2
S Normae							
a	144480	16	1.0	−57	40	6.61	A0
b	144858	16	2.8	−55	48	7.19	B5
c	144860	16	2.8	−57	20	7.60	B8
d	145417	16	5.7	−57	16	8.03	G5
RW Trianguli Australis							
a	....	16	51.8	−66	24	10.65	K7
b	....	16	52.8	−66	30	11.52	K2
c	....	16	55.8	−66	36	11.84	..

TABLE III.—*Cont.*

Star	H.D.	R.A. 1900		Dec. 1900		Adopted Pg. Mag.	Spectrum
RV Scorpii		*h*	*m*	°	′		
a	152820	16	50.6	−33	6	6.94	K5
b	153136	16	52.5	−33	22	7.90	A5
c	153154	16	52.6	−33	16	8.54	A0
BF Ophiuchi							
a	154132	16	58.5	−25	30	6.94	A5
b	153636	16	55.5	−26	48	8.04	A0
c	153873	16	56.9	−26	57	8.54	K0
d	....	16	55.6	−26	7	9.10	A2
X Sagittarii							
a	165135	17	59.4	−30	26	4.20	K0
b	163685	17	52.3	−28	45	5.80	B5
c	161756	17	42.2	−26	57	6.34	B3
RY Scorpii							
a	161612	17	41.4	−33	58	7.05	G5
b	162222	17	44.8	−33	49	8.43	A0
c	162122	17	44.3	−33	55	9.44	A0
d	....	17	44.2	−33	52	10.34	F0
S Arae							
a	163237	17	50.0	−49	7	9.62	A0
b	163542	17	51.5	−49	28	10.17	A0
c	163340	17	50.5	−49	14	10.41	A0
d	....	17	51.6	−49	23	10.96	B9
e	....	17	51.4	−49	26	11.15	G0
W Sagittarii							
a	165135	17	59.4	−30	26	4.20	K0
b	163685	17	52.3	−28	45	5.80	B5
c	165365	18	0.5	−28	23	6.96	A0
AP Sagittarii							
a	165921	18	3.2	−24	1	7.43	B0
b	166107	18	4.0	−23	48	7.85	B5
c	166191	18	4.4	−23	35	8.51	F5

TABLE III.—*Cont.*

Star	H.D.	R.A. 1900		Dec. 1900		Adopted Pg. Mag.	Spectrum
WZ Sagittarii		h	m	°	′		
a	167659	18	11.1	−19	0	7.48	B2
b	167375	18	9.8	−18	59	8.18	B
c	167520	18	10.5	−19	0	9.08	B8
d	....	18	11.4	−19	8	10.06	B3
e	....	18	10.9	−19	3	10.58	B8
XX Sagittarii							
a	168971	18	17.3	−17	4	8.83	A0
b	169457	18	19.6	−16	34	9.47	F2
c	169634	18	20.5	−16	49	9.98	G5
d	169228	18	18.6	−16	58	10.47	A2
e	....	18	20.0	−16	49	11.02	..
X Scuti							
a	170989	18	27.2	−13	8	9.80	A0
b	....	18	26.8	−13	14	10.92	B3
c	....	18	26.4	−13	12	11.31	G0
d	....	18	25.9	−13	16	11.98	A7
U Sagittarii							
a	170433	18	24.3	−18	47	7.23	K0
b	170657	18	25.5	−18	58	8.20	K0
c	170719	18	25.8	−19	9	8.95	B9
d	170860	18	26.5	−19	10	9.74	B9
Y Scuti							
a	172217	18	33.9	−8	35	9.66	K0
b	....	18	31.3	−8	31	10.94	F0
c	....	18	33.0	−8	29	11.17	B9
d	....	18	32.3	−8	26	11.45	B9
e	....	18	33.5	−8	30	11.75	B5
RU Scuti							
a	172593	18	36.0	−3	55	9.84	K2
b	....	18	35.9	−4	28	10.94	B2
c	....	18	36.1	−4	19	11.11	G0
d	....	18	36.1	−4	17	11.63	..
e	....	18	36.4	−4	2	11.83	G5

TABLE III.—*Cont.*

Star	H.D.	R.A. 1900		Dec. 1900		Adopted Pg. Mag.	Spectrum
Z Scuti		*h*	*m*	°	′		
a	173005	18	38.1	−5	48	9.05	K2
b	173006	18	38.1	−5	53	10.04	B3
c	....	18	38.3	−5	50	10.95	B8
d	....	18	38.5	−5	40	11.80	B9
e	....	18	37.6	−5	48	12.10	F5
SS Scuti							
a	173219	18	39.1	−7	13	8.18	B0p
b	173202	18	39.0	−7	44	8.79	F0
c	172852	18	37.3	−7	48	9.79	A0
d	172810	18	37.1	−7	44	10.62	K2
YZ Sagittarii							
a	172984	18	38.0	−17	2	7.57	A2
b	172904	18	37.6	−16	53	8.32	A0
c	174113	18	43.8	−17	1	8.51	B9
d	173927	18	42.9	−17	8	8.91	K0
BB Sagittarii							
a	174115	18	43.8	−19	15	7.13	A0
b	174651	18	46.4	−20	19	8.48	A0
c	174652	18	46.4	−20	26	9.13	B9
κ Pavonis							
a	173948	18	43.0	−62	18	4.23	B2
b	172555	18	35.7	−64	58	5.03	A2
c	179366	19	7.1	−66	50	5.61	A2
d	175986	18	52.8	−68	54	6.23	G0

TABLE IV

PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS

SECTION A

J. D. and	V Cen		U Nor		R TrA		S TrA		U TrA	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
14865.57f	5.08	7.39	1.64	10.64	2.85	7.65	0.61	6.66	....	....
15109.75f	2.03	7.74	5.61	11.19	3.00	7.33	....	....	0.22	8.13
15147.73f	1.55	7.66	5.66	11.12	0.30	7.11	4.54	7.76	2.23	8.67
15220.60f	3.00	7.83	2.68	10.64	2.00	7.91	....	....	0.62	8.73
15474.66f	4.33	8.00	3.89	10.92	1.86	8.00	2.64	7.20	0.42	8.43
15514.66f	0.38	7.07	5.96	11.33	1.19	7.65	4.70	7.76	1.89	8.84
15590.61f	4.91	7.57	6.05	11.26	....	....	4.77	7.68	0.79	8.70
15635.52f	0.37	7.07	0.39	9.83	0.04	7.06	5.41	7.20	2.04	8.62
15872.76f	1.37	7.39	10.06	10.98	0.03	7.08	2.36	7.20	0.42	8.24
15885.63f	3.25	8.00	10.29	10.86	2.73	7.82	2.58	7.20	0.45	8.20
15898.59f	5.22	6.99	10.61	10.86	2.13	8.09	2.89	7.44	0.57	8.46
15933.64f	1.81	7.74	7.73	11.36	3.29	7.06	0.00	6.37	2.23	8.62
15940.51f	3.19	8.00	1.96	10.54	3.38	7.14	0.55	6.58	1.40	8.62
15942.66f	5.34	6.92	4.11	10.98	2.14	8.09	2.70	7.28	0.98	8.67
16240.59f	....	....	11.26	10.70	1.81	8.09	3.42	7.53	0.98	8.70
16242.65f	3.16	7.74	0.67	10.18	0.49	7.36	5.48	7.28	0.47	8.35
16249.72f	4.73	7.74	7.74	11.36	0.78	7.29	6.23	6.66	2.41	8.51
16264.67f	3.20	7.92	10.05	10.86	2.17	8.09	2.21	7.36	1.95	8.84
16298.60f	4.16	8.00	6.05	11.26	2.21	8.09	4.52	7.84	2.49	8.13
16309.55f	4.13	7.92	4.36	11.16	2.99	7.65	2.82	7.36	0.60	8.57
16361.53f	1.17	7.30	5.77	11.16	0.74	7.65	....	....	1.21	8.81
16375.53f	4.18	8.00	7.13	11.36	1.18	7.65	5.57	7.36	2.37	8.46

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

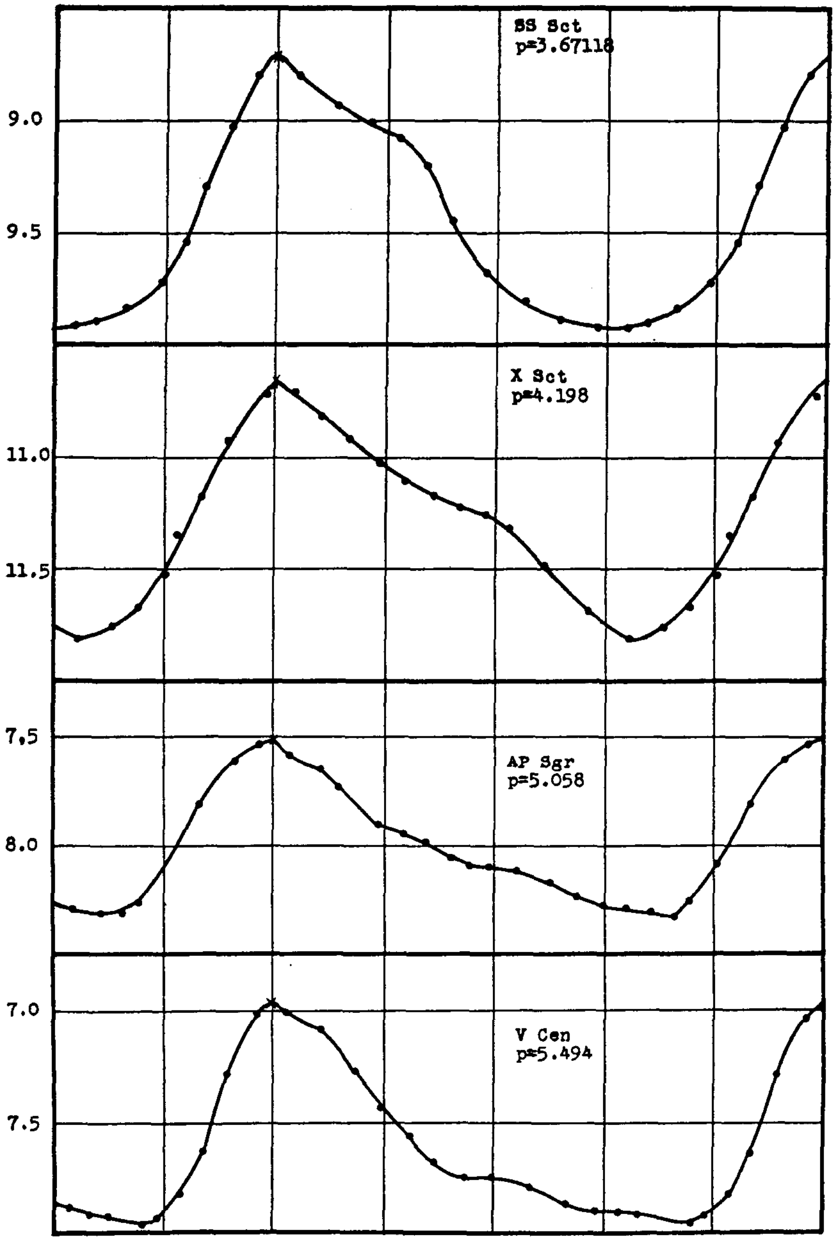
SECTION A

J. D. and	V Cen		U Nor		R TrA		S TrA		U TrA	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
16496.86f	4.64	7.92	2.03	10.54	0.50	7.48	0.42	6.51	0.42	8.24
16557.87f	5.21	7.07	....	.....	0.50	7.56	....	....	2.35	8.40
16563.77f	0.13	6.99	5.73	11.29	3.01	7.91	4.10	7.61	0.55	8.46
16589.71f	4.09	8.00	6.38	11.26	1.84	8.09	4.74	7.84	0.81	8.40
16607.76f	0.16	6.92	11.79	10.24	2.94	7.74	3.82	7.76	0.88	8.62
16617.66f	4.57	7.83	9.05	11.16	2.67	7.82	1.08	6.80	0.50	8.20
16636.68f	1.61	7.57	2.78	10.76	1.36	7.91	1.13	7.04	1.55	8.84
16647.64f	1.59	7.74	1.10	10.24	2.15	7.91	5.76	6.96	2.23	8.67
16664.61f	2.07	7.74	5.42	11.09	2.17	8.00	3.76	7.84	1.22	8.67
16684.56f	0.05	6.99	0.09	9.76	1.79	8.09	4.74	7.61	0.63	8.51
16918.77f	3.51	7.92	6.73	11.22	2.14	8.18	4.98	7.53	1.12	8.73
16951.70f	3.47	7.92	1.73	10.54	1.17	7.65	6.29	6.37	0.66	8.28
16971.63f	1.43	7.57	9.02	11.16	0.77	7.36	0.93	7.04	0.04	8.13
16979.60f	3.90	7.92	4.35	11.16	1.96	8.09	2.57	7.20	0.31	8.28
17018.63f	4.48	7.83	.....	.....	0.32	7.22	3.66	7.61	....	....
17035.62f	4.98	7.22	9.80	10.86	0.37	7.36	1.68	7.20	2.39	8.13
17069.58f	0.48	6.99	5.83	11.26	0.43	7.25	4.02	7.84	0.40	8.13
17087.54f	1.96	7.66	11.15	10.59	1.44	8.00	3.01	7.44	0.38	8.20
17094.54f	3.47	8.00	5.50	11.12	1.66	8.09	3.69	7.61	2.24	8.73
17238.87f	4.95	7.57	10.76	10.76	0.25	7.33	2.58	7.28	0.18	8.28
17297.75f	3.40	7.83	6.43	11.33	1.52	8.09	4.55	7.84	2.55	7.83
17341.75f	3.45	7.92	12.50	9.76	1.46	8.09	4.28	7.84	0.32	8.13
17375.63f	4.36	7.92	8.46	11.22	1.44	7.91	0.22	6.51	0.81	8.51
17405.65f	1.42	7.48	0.55	9.83	0.96	7.65	4.95	7.76	0.01	8.05

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS—*Cont.*

SECTION A

J. D. and	V Cen		U Nor		R TrA		S TrA		U TrA	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
17416.54f	1.32	7.48	11.44	10.33	1.88	7.91	3.19	7.53	0.63	8.28
17704.58f	3.67	7.92	8.70	11.22	1.63	8.04	0.35	6.58	1.02	8.73
17709.71f	3.31	8.00	1.18	10.33	3.37	7.08	5.48	7.20	1.01	8.78
17711.62f	5.22	6.99	3.09	10.76	1.89	8.00	1.06	7.04	0.35	8.20
17727.66f	4.77	7.74	6.49	11.36	0.99	7.56	....	....	0.98	8.73
17758.58f	2.73	7.92	12.13	9.83	1.40	8.09	3.76	7.68	1.08	8.78
17774.57f	2.24	7.74	2.83	10.81	0.45	7.36	0.78	6.58	1.66	8.78
17992.83f	0.74	7.07	6.17	11.29	1.79	8.09	4.03	7.92	1.61	8.84
18036.82f	0.77	7.07	.....	.....	1.72	8.00	3.76	7.76	1.94	8.89
18042.77f	1.23	7.48	7.53	11.19	0.89	7.91	2.39	7.36	0.19	8.20
18069.75f	0.74	7.97	7.23	11.36	0.76	7.82	5.07	7.53	1.48	8.73
18083.71f	3.71	8.00	8.55	11.22	1.16	7.91	0.06	6.37	0.03	8.13
18102.56f	0.58	6.99	2.11	10.64	3.07	7.33	6.26	6.88	0.90	8.62
18102.64f	0.66	7.07	2.19	10.76	3.15	7.25	0.02	6.51	0.98	8.67
18126.57f	2.62	7.92	0.84	10.13	3.35	7.25	4.98	7.84	1.80	8.78
18144.54f	4.11	8.00	6.16	11.36	0.99	7.82	3.98	7.68	1.79	8.84
18160.52f	3.60	8.00	9.50	10.98	0.02	7.06	0.99	6.66	2.36	8.67
18385.78f	3.61	7.92	.....	.....	1.59	8.00	4.92	7.84	1.61	8.78
18394.71f	1.55	7.48	3.48	10.81	0.35	7.33	1.21	7.12	0.26	7.98
18414.81f	5.17	7.15	10.94	10.86	0.11	7.11	2.34	7.28	2.39	7.83
18434.73f	3.11	7.92	5.57	11.16	3.09	7.36	3.29	7.36	1.76	8.84
18440.76f	3.65	8.00	11.60	10.24	2.34	8.09	2.99	7.44	0.08	8.20
18450.61f	2.51	7.74	8.81	11.03	2.02	8.09	0.20	6.58	2.23	8.62
18453.59f	0.00	6.92	11.79	10.13	1.61	8.09	3.18	7.44	0.07	8.20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7.5
V Cen
p=5.494

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	V Cen		U Nor		R TrA		S TrA		U TrA	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
18476.51f	0.94	7.22	9.42	11.12	0.81	7.33	0.80	6.66	2.45	8.13
18478.72f	3.15	7.92	11.63	10.28	3.02	7.29	3.01	7.36	2.09	8.73
18497.63f	0.08	6.99	5.26	11.12	1.59	8.09	2.95	7.28	0.45	8.28
18498.54f	0.99	7.22	6.17	11.22	2.50	8.00	3.86	7.76	1.36	8.84
18506.58f	3.54	7.92	1.57	10.64	0.37	7.33	5.58	7.04	1.70	8.67
18533.51f	3.00	7.83	3.21	10.92	0.19	7.33	0.89	7.04	0.37	8.20
18750.77f	0.50	7.07	.....	.....	0.53	7.40	3.15	7.44	1.89	8.84
18779.84f	2.10	7.83	9.33	10.98	2.49	7.82	0.60	6.88	0.14	7.98
18797.74f	3.52	8.00	1.94	10.64	0.05	7.11	5.85	6.96	0.07	7.83
18823.68f	1.98	7.83	2.60	10.86	2.27	8.09	0.18	6.66	0.32	8.13
18859.58f	4.92	7.57	0.57	10.13	0.89	7.82	4.46	7.84	0.26	8.13
18861.58f	1.43	7.74	2.57	10.86	2.89	7.74	0.13	6.66	2.26	8.73
18884.55f	2.42	7.74	0.26	9.83	2.13	7.91	4.13	7.76	2.12	8.73
19136.83f	1.97	7.83	12.33	9.83	0.21	7.08	3.47	7.36	0.13	8.20
19196.64f	1.35	7.74	8.92	11.09	2.41	8.09	0.05	6.58	0.87	8.78
19203.57f	2.79	7.92	3.21	10.86	2.56	7.82	0.65	6.88	0.10	8.20
19226.55f	3.79	7.92	0.90	10.38	1.81	7.91	4.66	7.92	2.53	7.98
19234.59f	0.84	7.07	8.94	11.09	3.07	7.06	0.05	6.58	0.30	8.20
19239.59f	0.35	7.07	.....	.....	1.30	7.82	5.05	7.84	0.17	7.91
19253.55f	3.32	7.83	2.62	10.86	1.70	8.00	0.04	6.37	1.28	8.73
19254.54f	4.31	8.00	3.61	10.86	2.69	7.91	1.03	6.96	2.27	8.46
19531.73f	1.30	7.48	.....	.....	1.96	8.00	6.31	6.51	2.08	8.73
19540.71f	4.79	7.74	11.64	10.13	0.77	7.74	2.64	7.28	0.79	8.62
19543.71f	2.30	7.83	.....	.....	0.38	7.18	5.64	6.88	1.22	8.84

TABLE IV.—Photographic Observations of Cepheid Variable Stars.—*Cont.*

Section A

J. D. and	V Cen		U Nor		R TrA		S TrA		U TrA	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
19557.72f	5.32	6.99	3.36	10.86	0.83	7.74	0.68	6.88	2.39	8.51
19559.66f	1.76	7.66	5.30	11.22	2.77	7.82	2.62	7.28	1.76	8.84
19572.61f	3.73	7.92	5.61	11.36	2.17	8.09	2.93	7.28	1.87	8.78
19589.64f	4.27	8.00	10.00	10.86	2.25	7.91	0.99	6.80	0.92	8.73
19604.59f	2.74	7.83	12.31	9.83	0.25	7.06	3.29	7.28	0.46	8.13
20019.51f	0.11	6.99	10.02	10.86	1.68	8.00	0.85	6.88	1.87	8.73
20033.51f	3.13	8.00	11.38	10.59	2.12	7.91	2.21	7.20	0.46	8.40
20045.52f	4.15	8.00	10.74	10.86	0.58	7.25	1.57	7.20	2.20	8.78
20278.73f	1.11	7.57	3.74	11.12	3.31	7.06	0.81	6.88	1.69	8.89
20279.75f	2.13	7.66	4.76	11.26	0.94	7.74	1.83	7.20	0.14	7.91
20287.68f	4.57	7.83	0.05	9.91	2.10	8.09	3.43	7.68	0.37	8.40
20314.62f	4.04	8.00	1.70	10.64	1.92	8.00	....	....	1.63	8.78
20325.62f	4.05	7.92	0.06	9.83	2.75	7.74	3.43	7.36	2.35	8.20
20326.55f	4.98	7.57	0.99	10.54	0.29	7.08	4.36	7.84	0.71	8.67
20332.56f	0.00	6.99	7.00	11.33	2.92	7.25	4.05	7.68	1.59	8.78
20338.58f	0.53	6.99	0.38	10.08	2.16	8.00	3.75	7.68	2.47	8.20
20349.60f	0.56	7.15	11.40	10.48	3.01	7.25	2.12	7.36	0.65	8.46
20358.54f	4.01	8.00	7.70	11.26	1.78	8.00	4.73	7.68	1.88	8.89
20389.53f	2.03	7.74	0.76	10.33	2.27	8.00	4.11	7.76	2.05	8.73
20392.53f	5.03	7.57	3.76	11.03	1.88	7.91	....	....	2.48	8.13
20607.76f	....	....	4.06	11.16	0.19	7.22	1.01	6.96	1.97	8.84
20612.84f	....	....	9.14	11.06	1.88	7.91	6.09	7.04	1.92	8.78
20681.60f	2.92	7.74	2.05	10.48	2.86	7.82	5.29	7.36	1.33	8.78
20688.62f	4.44	8.00	9.07	11.09	3.10	7.33	5.99	6.96	0.65	8.20

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	V Cen		U Nor		R TrA		S TrA		U TrA	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
20695.60f	0.44	7.07	3.40	10.92	3.30	7.22	0.32	6.88	2.49	8.13
20709.54f	3.39	8.00	4.70	11.16	0.29	7.29	1.62	7.20	1.02	8.67
20720.55f	3.41	7.83	3.07	10.86	1.14	7.91	6.30	6.37	1.76	8.84
20747.48f	2.87	7.92	4.71	11.16	0.95	7.82	1.61	7.20	0.44	8.20
20756.48f	0.88	7.39	1.07	10.33	3.17	7.22	4.29	7.84	1.73	8.73
20757.50f	1.90	7.74	2.09	10.59	0.80	7.65	5.31	7.28	0.18	7.98
20935.89f	4.48	7.92	3.48	11.06	2.95	7.36	0.32	6.58	1.36	8.84
20959.77f	0.89	7.48	2.08	10.70	3.11	7.29	5.23	7.44	2.12	8.78
20990.63f	4.28	7.92	7.65	11.22	0.07	7.22	4.47	7.92	2.16	8.84
20991.73f	5.38	7.07	8.75	11.09	....	....	....	....	0.69	8.28
21006.67f	3.84	7.92	11.05	10.64	2.56	8.00	1.54	7.28	0.22	8.20
21007.68f	4.85	7.74	12.06	9.91	0.18	7.11	2.55	7.28	1.23	8.67
21009.70f	1.38	7.66	1.44	10.59	2.20	8.00	4.57	7.84	0.69	8.40
21022.68f	....	....	.....	.....	1.62	7.91	4.90	7.92	0.82	8.73
21046.54f	5.25	7.15	0.35	10.08	1.76	7.82	3.47	7.68	1.57	8.73
21049.55f	2.77	7.83	3.36	10.86	1.38	7.82	0.11	6.66	2.01	8.84
21050.55f	3.77	7.92	4.36	11.16	2.38	7.91	1.15	6.88	0.44	8.57
21080.55f	....	....	9.07	11.12	1.87	7.91	5.86	6.88	2.19	8.67
21081.54f	....	....	10.06	10.86	2.86	7.74	0.53	6.51	0.61	8.57
21127.49f	3.79	8.00	.....	.....	1.36	7.82	2.21	7.36	0.33	8.20
21332.84f	....	....	8.51	11.12	3.36	7.03	5.21	7.68	0.21	8.05
21336.76f	4.29	7.83	12.43	9.91	....	....	2.80	7.20	1.57	8.78
21344.76f	1.30	7.48	7.78	11.22	....	....	4.48	7.68	1.86	8.84
21361.70f	1.76	7.74	12.09	9.91	1.71	8.00	2.45	7.20	0.82	8.51

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	V Cen		U Nor		R TrA		S TrA		U TrA	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
21367.67f	2.23	7.74	5.41	11.29	0.90	7.82	2.10	7.36	1.66	8.73
21370.71f	5.27	7.15	8.45	11.22	0.55	7.65	5.14	7.44	2.13	8.73
21390.67f	3.26	7.83	3.13	10.86	....	....	6.12	6.88	1.54	8.89
21391.66f	4.25	7.83	4.12	11.19	....	....	0.79	6.96	2.53	8.13
21396.65f	....	....	9.11	11.29	2.77	7.82	5.78	6.88	2.38	8.13
21397.66f	....	....	.....	.....	0.39	7.22	0.47	6.51	0.83	8.73
21400.61f	2.21	7.66	0.43	10.13	....	....	3.42	7.28	1.21	8.67
21402.60f	4.20	7.92	2.42	10.76	1.94	8.00	5.41	7.28	0.63	8.20
21421.53f	1.15	7.48	8.70	11.03	0.53	7.65	5.37	7.36	1.58	8.78
21424.54f	4.16	7.92	11.71	10.18	0.16	7.14	2.05	7.28	2.02	8.73
21428.52f	2.65	7.74	3.05	10.86	0.75	7.33	6.03	6.58	0.87	8.67
21430.50f	4.63	7.74	5.03	11.19	2.73	7.82	1.69	7.20	0.28	8.13
21431.50f	0.13	6.99	6.03	11.36	0.34	7.11	2.69	7.28	1.28	8.67
21440.50f	3.64	7.92	2.39	10.86	2.56	7.82	5.37	7.36	0.00	7.98
21449.54f	....	....	11.43	11.36	1.43	8.00	1.76	7.28	1.34	8.78
21731.68f	3.64	7.83	2.79	10.86	2.26	7.82	5.66	7.04	0.96	8.67
21749.67f	5.14	7.07	8.13	11.36	....	....	4.68	7.68	0.97	8.78
21751.66f	1.64	7.57	10.12	10.86	....	....	0.35	6.80	0.40	8.46
21755.66f	0.15	6.92	1.48	10.70	....	....	4.35	7.76	1.83	8.84
21756.69f	....	....	2.51	10.86	0.16	7.08	5.38	7.28	....	....
21758.67f	3.16	7.74	4.49	11.26	....	....	1.04	7.04	2.27	8.73
21776.58f	4.58	7.74	9.76	10.86	3.10	7.36	6.30	6.37	2.20	8.62
21789.54f	1.06	7.30	10.08	10.76	2.50	7.74	0.29	6.58	2.32	8.51
21790.54f	2.06	7.66	11.08	10.59	0.11	7.18	1.29	7.04	0.75	8.46

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	V Cen		U Nor		R TrA		S TrA		U TrA	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
21870.49f	5.10	7.30	2.53	10.64	....	....	5.35	7.28	1.08	8.73
22100.65f	4.51	7.83	5.12	11.29	1.80	8.00	1.54	7.28	0.09	7.83
22108.62f	1.49	7.48	0.45	10.13	2.99	7.48	3.19	7.44	0.36	8.13
22129.60f	....	....	8.78	11.29	0.24	7.11	....	....	0.79	8.40
22131.66f	2.55	7.74	10.84	10.64	....	....	0.94	6.96	0.28	8.13
22136.64f	2.04	7.83	3.18	10.86	....	....	5.92	7.04	....	....
22138.54f	....	....	5.08	11.29	2.41	7.82	....	....	2.02	8.78
22175.56f	....	....	4.17	11.12	2.14	8.09	0.57	6.66	0.52	8.13
22193.54f	....	....	9.51	11.19	3.18	7.14	5.90	6.96	0.52	8.28
22196.51f	1.47	7.74	12.48	9.91	....	....	2.55	7.20	0.92	8.73
22455.70f	2.44	7.66	6.17	11.26	0.97	7.65	2.47	7.28	0.71	8.28
22517.51f	3.82	7.83	4.77	11.19	1.77	8.00	1.05	6.96	0.88	8.51
22541.53f	0.37	6.99	.....	.....	....	....	6.10	6.37	1.79	8.78
22542.55f	....	....	4.53	11.29	3.09	7.25	0.79	6.66	0.24	8.13
23180.68f	2.21	7.74	10.52	10.64	0.64	7.74	0.24	6.51	1.42	8.78
23197.74f	2.79	7.74	2.30	10.81	0.76	7.74	4.66	7.92	0.50	8.05
23199.60f	4.65	7.74	.....	.....	2.62	7.74	0.19	6.51	2.36	8.13
23209.68f	3.74	7.92	1.59	10.64	2.53	8.00	3.95	7.92	2.17	8.78
23221.55f	4.62	7.74	0.82	10.13	0.84	7.82	3.17	7.36	....	....
23228.58f	0.67	7.15	.....	.....	1.09	7.74	3.88	7.61	0.52	8.13
23229.64f	1.72	7.74	.....	.....	2.15	7.91	3.94	7.76	1.58	8.84
23232.60f	4.68	7.66	11.87	9.99	....	....	....	....	1.97	8.67
23234.57f	1.16	7.48	1.20	10.48	0.31	7.29	3.55	7.44	1.37	8.73
23237.54f	4.13	7.92	4.17	11.12	3.28	7.25	0.19	6.58	1.78	8.96
23253.54f	3.65	7.83	7.53	11.29	2.33	7.82	3.55	7.44	2.37	8.57

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	V Cen		U Nor		R TrA		S TrA		U TrA	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
23283.52f	0.66	6.99	12.22	9.99	1.81	7.91	1.91	7.20	1.53	8.73
23533.72f	3.63	7.83	9.57	10.86	1.20	8.00	5.49	7.20	0.03	7.83
23566.72f	3.67	7.92	.....	.....	0.31	7.22	0.55	6.66	2.21	8.51
23575.67f	1.63	7.66	0.95	10.08	2.48	8.00	3.17	7.36	0.88	8.67
23647.52f	2.06	7.74	9.58	10.98	3.15	7.56	5.47	7.20	0.82	8.51
23902.78z	4.59	7.83	11.99	9.83	0.83	7.91	1.46	7.12	1.82	8.89
23918.70z	4.03	7.92	2.63	10.98	3.19	7.03	4.74	7.76	2.33	8.62
23941.70z	5.05	7.15	0.34	10.24	....	....	2.44	7.28	2.21	8.73
23961.58z	2.95	7.74	7.58	11.26	2.01	7.91	3.35	7.36	1.54	8.78
23972.56z	....	....	5.91	11.33	2.82	7.48	1.68	7.12	2.25	8.73
23996.53z	4.94	7.66	4.60	11.33	3.07	7.40	0.36	6.66	0.54	8.46
24025.51z	0.96	7.74	8.29	11.19	1.54	7.82	4.04	7.92	1.27	8.67
24245.82z	1.50	7.48	1.04	10.59	1.55	7.82	3.03	7.28	0.70	8.73
24294.70z	0.94	7.30	11.99	10.08	2.98	7.36	1.32	6.96	0.78	8.40
24327.63z	0.90	7.57	6.99	11.36	2.02	8.26	2.63	7.28	0.32	8.13
24353.56z	....	....	7.63	11.26	0.83	8.00	3.27	7.68	0.57	8.51
24355.56z	1.36	7.66	9.63	10.86	2.83	7.91	....	....	....	....
24359.50z	5.30	6.99	0.93	10.13	3.38	7.25	2.88	7.36	1.37	8.73
24375.50z	4.82	7.74	4.29	10.98	2.44	8.00	6.24	6.58	1.96	8.84
24621.72z	3.81	7.83	10.30	10.76	1.24	7.82	....	....	1.62	8.73
24641.79z	1.90	7.66	5.08	11.16	....	....	0.61	6.96	1.14	8.67
24733.51z	0.22	7.07	8.30	11.19	1.18	8.00	3.80	7.76	2.43	8.51
25328.51z	1.87	7.83	9.10	11.19	3.06	7.56	4.39	7.76	2.12	8.84
25382.48z	0.90	7.48	12.50	9.91	2.80	7.91	1.45	7.04	2.15	8.67
25440.28z	3.76	7.92	7.09	11.36	....	....	2.33	7.20	0.88	8.40

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	YZ Sgr		WZ Sgr		AP Sgr		XX Sgr		U Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
14862.62f	....	....	3.48	9.18	4.71	7.47	2.84	10.69	2.22	8.42
14904.57f	6.72	8.51	1.73	8.63	1.14	8.05	6.25	9.41	3.70	8.80
15148.73f	2.50	8.67	5.57	9.66	2.51	8.31	6.28	9.34	5.04	9.11
15532.70f	4.34	8.79	18.13	10.06	2.06	8.05	4.80	10.86	4.55	9.03
15634.57f	1.12	8.38	10.77	10.22	2.77	8.25	3.88	10.86	5.25	8.88
15872.81f	0.54	8.32	8.68	10.06	3.27	8.25	4.42	10.96	0.67	8.01
15885.83f	4.00	8.75	21.70	8.04	1.12	7.85	4.59	10.86	0.20	7.91
15897.70f	6.32	8.59	11.73	10.16	2.87	8.18	3.62	10.86	5.33	9.19
15933.68f	4.09	8.83	4.01	9.37	3.45	8.31	1.05	9.47	0.84	8.01
15934.65f	5.06	8.79	4.98	9.37	4.42	7.98	2.02	10.32	1.81	8.50
15940.64f	1.49	8.45	10.97	10.16	....	....	1.59	9.93	1.04	8.27
16023.57f	8.00	8.25	6.51	9.66	2.29	8.25	1.00	9.41	3.04	8.72
16241.73f	6.44	8.45	6.20	9.57	2.94	8.31	0.74	9.47	5.37	9.19
16253.71f	....	....	18.18	10.16	4.80	7.56	6.29	9.28	3.86	8.88
16297.69f	5.08	8.79	18.46	10.11	3.27	8.31	5.30	10.64	0.62	8.10
16311.63f	9.46	8.17	10.55	10.22	2.04	8.18	6.39	9.28	1.07	8.35
16319.54f	7.82	8.34	18.46	9.96	4.89	7.51	1.45	10.08	2.24	8.72
16359.61f	0.13	8.10	14.84	10.42	4.49	7.92	2.98	10.80	....	....
16376.62f	7.58	8.38	10.00	10.06	1.27	8.05	0.72	9.28	5.36	8.88
16593.79f	5.03	8.79	8.70	9.96	0.94	7.72	5.89	10.37	6.69	8.50
16608.89f	1.02	8.40	1.95	8.63	0.87	7.85	1.71	10.23	1.56	8.58
16636.77f	0.24	7.96	7.98	9.77	3.46	8.25	3.90	10.80	2.46	8.58
16650.72f	4.64	8.83	0.08	8.04	2.23	8.25	5.00	10.86	2.92	8.88
16663.80f	8.17	8.32	13.16	10.37	0.14	7.56	5.23	10.80	2.51	8.65

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	YZ Sgr		WZ Sgr		AP Sgr		XX Sgr		U Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
16697.67f	3.83	8.59	3.34	8.81	3.66	8.44	0.55	9.28	2.65	8.72
16943.84f	1.61	8.45	9.19	10.11	1.98	8.18	2.60	10.37	6.00	8.72
16968.80f	7.47	8.36	12.30	10.32	1.65	8.05	1.86	10.23	3.99	9.11
16979.77f	8.88	8.10	1.42	8.45	2.50	8.31	6.41	9.21	1.47	8.42
17004.65f	5.10	8.79	4.45	9.28	2.09	8.05	5.59	10.64	6.11	8.65
17009.77f	0.67	8.38	9.57	10.22	2.15	8.18	4.29	10.86	4.49	9.19
17032.77f	4.56	8.83	10.73	10.32	4.92	7.56	1.59	10.23	0.51	8.01
17076.67f	0.70	8.38	10.93	10.22	3.30	8.25	0.52	9.34	3.94	9.03
17077.65f	....	....	11.91	10.22	4.28	8.05	1.50	9.83	4.92	9.03
17105.61f	0.98	8.42	18.02	10.22	1.89	7.92	3.76	10.86	5.90	8.65
17335.80f	1.89	8.55	7.89	9.66	4.46	7.85	2.68	10.52	0.01	8.20
17360.72	7.71	8.38	10.96	10.16	4.09	8.25	1.90	10.32	4.70	9.11
17384.72f	3.05	8.67	13.12	10.32	2.80	8.31	0.21	9.28	1.72	8.50
17403.72f	2.94	8.55	10.27	10.11	1.57	7.85	6.36	9.34	0.49	8.20
17447.57f	8.58	8.34	10.42	10.16	4.96	7.47	5.24	10.86	3.87	9.07
17465.56f	7.46	8.36	6.57	9.57	2.71	8.25	3.96	10.86	1.62	8.58
17495.54f	8.78	8.17	14.70	10.42	2.34	8.18	1.81	9.93	4.62	9.19
17703.90f	6.97	8.45	4.58	9.28	3.32	8.44	4.60	10.86	3.89	9.11
17758.72f	....	....	5.71	9.77	2.50	8.18	1.60	10.03	4.75	9.19
17774.72f	1.37	8.51	9.86	10.06	3.33	8.31	4.75	10.86	0.52	8.20
17787.64f	....	....	0.93	8.27	1.07	7.77	4.82	10.86	6.69	8.27
17813.55f	1.99	8.45	5.00	9.28	1.69	7.98	5.04	10.86	5.62	8.88
17820.55f	8.99	8.10	12.00	10.37	3.63	8.31	5.61	10.74	5.88	8.72
18027.89f	6.16	8.59	0.86	8.45	3.59	8.25	0.95	9.62	4.12	9.03

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	YZ Sgr		WZ Sgr		AP Sgr		XX Sgr		U Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
18042.86f	2.02	8.43	15.83	10.27	3.39	8.25	3.07	10.64	5.60	8.88
18069.86f	0.36	8.03	20.98	8.45	0.04	7.47	4.38	10.86	5.62	9.03
18111.78f	....	....	19.21	10.11	1.49	7.98	1.33	9.73	0.33	8.10
18148.66f	2.74	8.51	12.39	10.32	2.97	8.25	6.08	10.42	3.48	9.03
18156.61f	1.13	8.42	20.34	9.28	0.80	7.92	1.19	9.93	4.69	9.11
18199.56f	5.87	8.63	19.60	10.06	3.28	8.25	5.59	10.74	0.43	8.10
18209.53f	6.29	8.55	7.72	9.66	3.14	8.31	2.71	10.47	3.65	8.95
18438.84f	6.32	8.55	18.56	10.11	4.83	7.56	0.75	9.62	3.63	8.80
18453.80f	2.18	8.55	11.67	10.22	4.62	7.56	2.86	10.64	5.10	9.03
18472.69f	1.96	8.45	8.71	9.96	3.27	8.25	2.48	10.58	3.76	8.88
18499.71f	0.32	8.10	13.88	10.42	5.00	7.47	3.80	10.91	3.80	8.95
18500.72f	1.33	8.45	14.89	10.42	0.96	7.92	4.81	10.86	4.81	9.11
18501.59f	2.20	8.55	15.76	10.37	1.83	8.05	5.68	10.52	5.68	8.84
18506.68f	7.29	8.43	20.85	8.63	1.86	8.18	4.35	10.91	4.02	8.88
18531.61f	3.56	8.75	2.09	8.63	1.50	7.92	3.58	10.74	1.97	8.42
18565.53f	8.82	8.32	14.16	10.37	0.01	7.51	5.38	10.80	2.17	8.65
18820.82f	6.18	8.55	7.28	9.77	2.39	8.18	3.70	10.91	1.15	8.10
18821.79f	7.15	8.45	8.25	9.86	3.36	8.31	4.67	10.96	2.12	8.42
18832.78f	8.58	8.17	19.24	9.96	4.24	8.18	2.81	10.52	6.37	8.72
18848.63f	5.33	8.75	13.24	10.37	4.91	7.47	5.81	10.47	1.98	8.50
18855.75f	2.89	8.59	20.36	9.18	1.92	8.25	0.08	9.28	2.36	8.65
18859.70f	6.84	8.55	2.47	8.81	0.81	7.92	4.03	10.80	6.31	8.27
18884.63f	3.11	8.51	5.55	9.77	0.45	7.85	3.26	10.69	4.26	9.03
18919.55f	9.37	8.32	18.62	10.16	5.02	7.56	6.06	9.47	5.45	9.19

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	YZ Sgr		WZ Sgr		AP Sgr		XX Sgr		U Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
19204.74f	7.97	8.34	19.79	10.06	1.90	8.11	2.16	10.32	0.61	8.01
19233.66f	8.23	8.18	5.02	9.57	0.47	7.72	5.38	10.69	2.55	8.62
19241.61f	6.63	8.55	12.97	10.37	3.36	8.38	0.49	9.41	3.76	8.84
19264.60f	0.96	8.34	14.11	10.42	1.06	8.05	4.20	10.96	6.51	8.20
19300.50f	8.20	8.34	6.32	9.77	1.55	8.05	1.56	9.88	1.94	8.35
19311.53f	0.13	8.10	17.35	10.16	2.46	8.05	6.16	9.41	6.23	8.65
19532.72f	1.59	8.45	20.06	9.77	1.10	7.98	2.50	10.64	4.84	8.95
19542.85f	2.17	8.49	8.34	10.11	1.11	7.85	6.21	9.62	1.48	8.42
19545.81f	5.13	8.75	11.30	10.42	4.07	7.98	2.75	10.52	4.44	9.03
19561.72f	1.93	8.49	5.37	9.66	4.81	7.47	5.81	10.52	0.11	8.10
19562.69f	2.90	8.55	6.34	9.77	0.72	7.98	0.35	9.28	1.08	8.01
19572.70f	3.36	8.59	16.35	10.22	0.61	7.64	3.94	10.96	4.35	9.03
19593.71f	5.26	8.79	15.51	10.48	1.39	7.98	5.68	10.58	5.12	9.11
19601.64f	3.64	8.79	1.59	8.63	4.26	7.92	0.76	9.62	6.31	8.27
19603.65f	5.65	8.71	3.60	9.18	1.21	7.85	2.77	10.52	1.57	8.42
19604.55f	6.55	8.55	4.50	9.28	2.11	8.11	3.67	10.86	2.47	8.58
19632.58f	5.92	8.67	10.68	10.22	4.85	7.47	6.00	9.93	3.52	8.72
19645.63f	9.41	8.02	1.89	8.72	2.73	8.31	6.20	9.34	3.08	8.72
19650.65f	4.88	8.75	6.91	9.77	2.69	8.18	4.80	11.02	1.36	8.35
19657.56f	2.24	8.55	13.82	10.58	4.54	7.60	....	.....	1.52	8.15
19889.88f	5.28	8.79	5.81	9.77	4.19	7.92	6.33	9.28	4.52	9.11
19898.87f	4.72	8.75	14.80	10.48	3.06	8.31	2.47	10.58	0.02	7.91
19912.80f	9.10	8.10	6.89	9.77	1.82	8.18	3.55	10.91	0.46	8.01
19922.82f	0.01	8.10	16.91	10.22	1.72	8.05	0.72	9.47	3.73	9.03

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	YZ Sgr		WZ Sgr		AP Sgr		XX Sgr		U Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
19931.66f	8.85	8.10	3.90	9.18	0.44	7.51	3.14	10.58	5.83	9.03
19942.76f	0.84	8.38	15.00	10.58	1.43	7.92	1.39	10.13	3.44	8.72
19947.72f	5.80	8.59	19.96	9.77	....	....	6.35	9.28	1.65	8.50
19950.71f	8.79	8.10	1.10	8.45	4.32	7.77	2.92	10.58	4.64	9.03
19951.72f	0.25	8.09	2.11	8.81	0.27	7.47	....	.....	5.65	8.80
19959.58f	8.11	8.34	9.97	10.11	3.07	8.18	5.36	10.64	0.02	8.20
19961.60f	0.58	8.18	11.99	10.22	0.04	7.43	0.96	9.73	2.04	8.65
19973.51f	2.93	8.55	2.05	8.72	1.83	7.98	0.02	9.21	0.46	7.91
19977.67f	7.09	8.45	6.21	9.77	0.93	7.92	4.18	11.02	4.62	9.03
19985.52f	5.39	8.79	14.06	10.58	3.72	8.18	5.61	10.86	5.73	8.95
19989.52f	9.39	8.10	18.06	10.16	2.67	8.11	3.18	10.64	2.98	8.72
20012.57f	3.78	8.63	19.27	10.11	0.42	7.47	0.53	9.41	5.80	8.95
20013.56f	4.77	8.83	20.26	9.66	1.41	7.98	....	.....	0.04	7.96
20044.56f	7.11	8.43	7.56	9.86	2.07	8.18	0.42	9.41	4.06	8.88
20297.67f	2.29	8.55	20.35	9.37	2.27	7.98	2.97	10.64	0.87	8.01
20306.74f	1.80	8.47	7.57	9.86	1.22	7.98	5.61	10.64	3.19	8.72
20307.56f	2.62	8.59	8.39	10.16	2.04	7.98	0.01	9.34	....	....
20328.60f	4.56	8.83	7.58	9.86	2.85	8.25	1.78	10.27	4.82	9.19
20329.69f	5.65	8.79	8.67	10.11	3.94	8.18	2.87	10.69	5.91	9.03
20330.67f	6.63	8.51	9.65	10.16	4.92	7.47	3.85	10.86	0.14	7.91
20337.66f	4.06	8.71	16.64	10.58	1.79	7.92	4.41	10.96	0.39	7.91
20338.58f	4.98	8.83	17.56	10.37	2.71	8.25	5.33	10.80	1.31	8.35
20354.58f	1.88	8.47	11.72	10.37	3.54	8.31	2.06	10.32	3.82	9.03
20366.58f	4.33	8.75	1.87	8.54	0.37	7.56	1.21	9.62	2.33	8.50

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

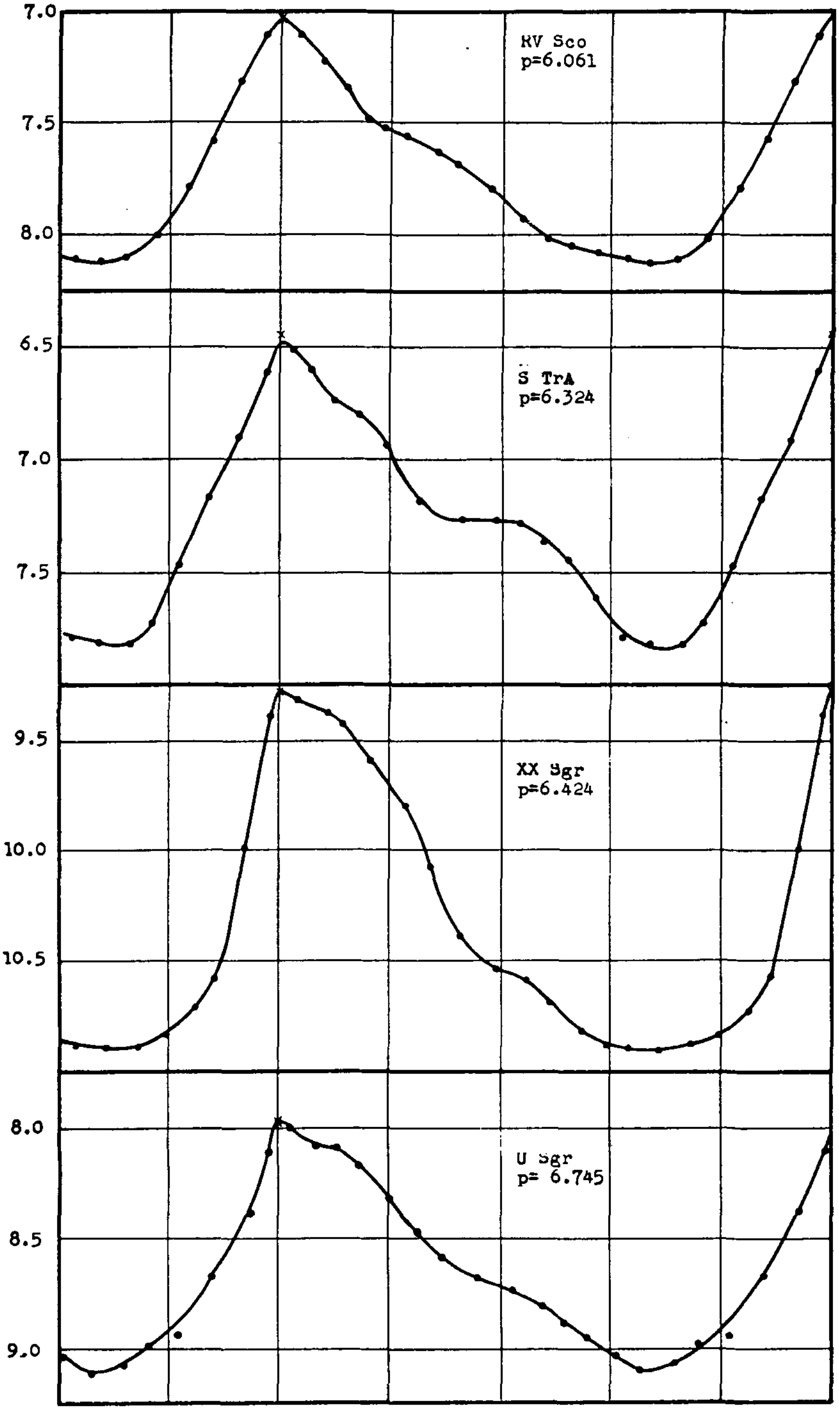
SECTION A

J. D. and	YZ Sgr		WZ Sgr		AP Sgr		XX Sgr		U Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
20367.59f	5.34	8.75	2.88	8.99	1.38	7.98	2.22	10.52	3.34	8.65
20372.62f	0.81	8.10	7.91	9.86	1.35	7.98	0.83	9.47	1.62	8.20
20384.53f	3.17	8.67	19.82	9.86	3.14	8.25	6.31	9.34	0.04	8.10
20394.58f	3.67	8.79	8.02	9.77	3.07	8.18	3.51	10.80	3.35	8.80
20414.54f	4.52	8.75	6.13	9.47	2.80	8.25	4.20	10.86	3.07	8.88
20610.85f	9.77	8.10	5.82	9.66	1.84	8.18	....	.....	3.78	8.95
20652.77f	3.92	8.63	4.04	9.18	3.30	8.31	4.73	10.86	5.23	9.03
20667.77f	9.37	8.18	19.04	9.96	....	....	0.46	9.34	0.00	8.20
20670.66f	2.70	8.51	0.08	8.27	....	....	3.35	10.74	2.89	8.72
20681.71f	4.20	8.75	11.13	10.32	1.89	8.25	1.55	9.78	0.45	8.20
20688.71f	1.65	8.40	18.13	10.11	3.83	8.25	2.13	10.52	0.70	8.01
20691.62f	4.56	8.79	21.04	8.72	1.68	7.98	5.04	10.96	3.61	9.03
20695.66f	8.60	8.18	3.24	9.18	0.67	7.85	2.65	10.52	0.91	8.20
20719.61f	3.89	8.79	5.34	9.28	4.38	8.05	0.91	9.52	4.62	9.07
20747.52f	3.14	8.55	11.40	10.42	1.95	7.98	3.12	10.64	5.55	9.03
20752.48f	8.10	8.38	16.36	10.37	1.85	8.25	1.65	10.03	3.77	8.88
20769.48f	5.99	8.63	11.51	10.42	3.67	8.18	5.81	10.52	0.53	8.01
21006.79f	4.47	8.87	8.50	9.96	3.25	8.31	5.42	10.80	1.77	8.42
21007.78f	5.46	8.83	9.49	10.11	4.24	7.92	6.41	9.28	2.76	8.50
21009.83f	7.51	8.40	11.54	10.42	1.23	7.98	2.03	10.23	4.81	9.19
21011.76f	9.44	8.03	13.47	10.58	3.17	8.31	3.96	10.91	0.00	8.10
21023.74f	2.32	8.45	3.61	9.18	5.03	7.56	3.10	10.58	5.23	8.95
21048.68f	8.15	8.34	6.70	9.66	4.64	7.47	2.34	10.47	3.19	8.88
21062.63f	3.00	8.55	20.65	8.90	3.45	8.18	3.44	10.86	3.65	8.95

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	YZ Sgr		WZ Sgr		AP Sgr		XX Sgr		U Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
21066.63f	7.00	8.51	2.80	9.18	2.39	8.18	1.02	9.78	0.91	8.20
21079.59f	0.85	8.38	....	.....	0.18	7.68	1.13	9.47	0.38	8.20
21080.60f	1.86	8.42	16.77	10.16	1.19	8.05	2.14	10.47	1.39	8.50
21092.54f	4.25	8.79	6.86	9.77	3.01	8.31	1.23	9.73	6.58	8.50
21099.55f	1.70	8.55	13.87	10.53	4.96	7.47	1.81	10.32	6.85	8.31
21103.55f	5.70	8.67	17.87	10.22	3.91	8.31	5.81	10.52	4.10	9.03
21135.52f	9.01	8.10	6.15	9.77	0.47	7.56	5.66	10.64	2.35	8.65
21137.53f	1.47	8.45	8.16	9.66	2.48	8.11	1.25	9.62	4.36	9.03
21155.49f	0.32	8.10	.....	.....	0.21	7.72	6.36	9.47	2.08	8.46
21156.51f	1.34	8.38	5.29	9.66	1.23	7.98	0.96	9.73	3.10	8.72
21160.50f	5.33	8.75	9.28	10.06	0.16	7.56	4.95	10.74	0.35	8.20
21364.83f	9.05	8.18	16.98	10.37	2.16	8.05	3.70	10.96	2.33	8.42
21393.75f	9.31	8.10	2.21	8.81	0.73	7.81	0.50	9.34	4.27	9.03
21398.70f	4.74	8.75	7.16	9.66	0.63	7.92	5.50	10.69	2.47	8.65
21399.71f	....	....	.....	.....	1.64	8.25	....	.....	....	....
21424.63f	1.98	8.59	11.24	10.42	1.27	8.05	5.68	10.58	1.43	8.58
21427.62f	4.97	8.79	14.23	10.42	4.26	7.85	2.25	10.52	4.42	9.11
21451.57f	....	....	.....	.....	2.91	8.38	....	.....	....	....
21453.54f	....	....	.....	.....	4.88	7.64	....	.....	....	....
21455.56f	....	....	.....	.....	1.85	8.18	....	.....	....	....
21457.56f	6.25	8.59	0.48	8.27	3.85	8.31	0.07	9.41	0.63	8.20
21460.54f	....	....	.....	.....	1.77	8.18	....	.....	....	....
21462.53f	....	....	.....	.....	3.76	8.38	....	.....	....	....
21523.54f	....	....	.....	.....	4.07	8.18	....	.....	....	....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7.5
8.0
RV Sco
p=6.061
6.5
7.0
7.5
S TrA
p=6.324
9.5
10.0
10.5
XX Sgr
p=6.424
8.0
8.5
9.0
U Sgr
p= 6.745

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	YZ Sgr		WZ Sgr		AP Sgr		XX Sgr		U Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
21788.63f	2.96	8.59	3.83	9.18	1.08	7.92	3.50	10.80	1.20	8.20
21806.66f	1.88	8.55	0.02	8.27	3.94	8.25	2.26	10.52	5.74	9.11
21817.56f	....	....	.....	.....	4.72	7.64	....	.....	....	....
21818.58f	....	....	.....	.....	0.68	7.51	....	.....	....	....
21819.56f	....	....	.....	.....	1.66	8.25	....	.....	....	....
21836.53f	....	....	.....	.....	3.46	8.38	....	.....	....	....
22135.68f	....	....	.....	.....	4.18	8.05	....	.....	....	....
22166.51f	8.26	8.34	10.31	10.16	....	....	2.35	10.64	1.36	8.20
22194.56f	....	....	.....	.....	2.36	8.25	....	.....	....	....
22225.53f	0.41	8.10	3.78	9.28	2.98	8.44	3.55	10.91	6.42	8.50
22516.60f	4.89	8.75	10.84	10.06	0.68	7.56	5.53	10.86	0.72	8.01
23181.82f	1.39	8.38	20.63	8.81	3.28	8.44	2.62	10.52	4.94	9.19
23194.75f	4.76	8.75	11.71	10.42	1.04	7.98	2.71	10.52	4.38	9.07
23205.65f	6.11	8.67	0.77	8.45	....	....	0.76	9.28	1.79	8.35
23206.69f	7.15	8.43	1.81	8.54	2.86	8.38	1.80	10.32	2.83	8.72
23209.72f	0.63	8.32	4.84	9.57	0.83	7.98	4.83	10.91	5.86	8.72
23222.72f	4.07	8.59	17.84	10.06	3.72	8.31	4.98	10.80	5.37	9.19
23235.68f	7.48	8.38	8.95	9.96	1.50	8.05	5.09	10.86	4.84	9.03
23247.66f	0.35	8.03	.....	.....	3.37	8.31	4.22	10.91	3.33	8.80
23248.59f	1.28	8.40	0.00	7.97	4.30	7.92	5.15	10.69	4.26	8.95
23253.61f	6.30	8.63	5.03	9.66	4.26	7.92	3.75	10.91	....	....
23277.57f	1.60	8.38	7.14	9.96	2.93	8.25	2.01	10.47	6.26	8.58
23306.51f	1.88	8.43	14.23	10.58	1.52	8.05	5.25	10.74	1.47	8.27
23311.52f	6.89	8.51	19.25	9.86	1.47	8.05	3.84	10.86	6.48	8.27

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	YZ Sgr		WZ Sgr		AP Sgr		XX Sgr		U Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
23346.52f	3.68	8.71	10.55	10.11	1.07	8.05	0.29	9.28	1.01	8.10
23535.78f	1.88	9.10	3.18	9.47	3.17	8.25	3.25	10.74	1.42	8.42
23561.73f	8.72	8.18	7.29	9.66	3.83	8.44	3.50	10.69	0.39	8.20
23576.78f	4.67	8.83	0.49	8.45	3.71	8.31	5.70	10.64	1.95	8.65
23662.53f	4.44	8.79	20.70	8.90	3.47	8.31	1.52	9.83	0.01	8.10
23664.56f	6.47	8.49	0.88	8.63	0.44	7.72	3.55	10.80	2.04	8.72
23905.83z	....	....	1.83	8.72	3.98	8.05	0.69	9.41	0.50	8.01
23919.72z	....	....	15.72	10.42	....	....	....	.....	....	....
23919.79z	3.76	8.55	15.79	10.58	2.77	8.11	1.81	9.98	0.97	8.27
23931.68y	....	....	5.83	9.57	....	....	....	.....	....	....
23934.68z	....	....	8.83	10.11	....	....	....	.....	....	....
23947.68z	....	....	21.83	8.27	....	....	....	.....	....	....
23960.58z	6.34	8.51	12.88	10.58	3.09	8.25	4.05	10.86	....	....
23965.71z	1.92	8.59	18.01	10.27	3.16	8.25	2.75	10.64	6.42	8.50
23969.70z	5.91	8.71	0.15	8.04	2.10	8.05	0.32	9.34	....	....
23993.64z	1.19	8.40	2.25	9.08	0.74	7.60	4.99	10.86	0.62	8.01
24020.57z	9.01	8.32	7.33	9.77	2.38	8.31	6.22	9.41	0.57	8.20
24023.58z	2.47	8.49	10.34	10.32	....	....	2.81	10.52	3.58	8.72
24033.57z	2.91	8.55	20.33	9.66	0.21	7.51	6.37	9.21	0.08	7.91
24232.86y	....	....	1.14	8.54	....	....	....	.....	....	....
24285.79z	6.74	8.55	10.38	10.16	....	....	1.62	9.83	2.74	8.72
24292.77z	....	....	17.36	10.16	1.44	8.05	....	.....	2.98	8.72
24300.80z	2.65	8.51	3.54	9.37	4.42	7.72	3.78	10.80	4.26	9.03
24325.74z	8.48	8.32	6.63	9.86	4.07	8.25	3.03	10.58	....	....

TABLE IV.—Photographic Observations of Cepheid Variable Stars.—*Cont.*

Section A

J. D. and	YZ Sgr		WZ Sgr		AP Sgr		XX Sgr		U Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
24404.52z	....	....	.....	.....	1.92	8.05	4.72	10.91	0.06	8.01
24432.53z	0.63	8.32	.....	.....	4.64	7.64	0.60	9.28	....	....
24731.64z	3.60	8.55	.....	.....	....	....	4.20	10.86	3.43	9.03
25035.67y	....	....	17.44	10.22	....	....	....	.....	....	....
25355.60z	6.60	8.55	9.66	10.27	2.07	8.05	5.00	11.02	0.11	8.01
25389.60z	2.39	8.47	21.81	7.90	....	....	0.46	9.34	0.38	8.20
25413.76r	7.44	8.38	.....	.....	....	....	....	.....	....	....
25443.66r	8.68	8.34	10.33	10.06	....	....	....	.....	0.48	7.91
25449.67r	....	....	16.34	10.42	....	....	....	.....	6.49	8.42
25801.70r	3.70	8.59	18.81	9.86	....	....	....	.....	1.04	8.06
25808.72r	1.17	8.34	.....	.....	....	....	....	.....	1.32	8.10
25824.64r	7.54	8.38	19.90	9.57	....	....	....	.....	3.75	8.72
25878.52r	4.10	8.71	8.24	9.77	....	....	....	.....	3.67	8.80
25889.51r	....	....	19.23	9.77	....	....	....	.....	1.17	8.10

J. D. and	Y Sct		Z Sct		RU Sct		X Sct		SS Sct	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
14876.60f	2.31	11.20	7.28	12.10	11.57	11.73	4.11	10.81	2.55	9.74
14890.60f	5.97	11.66	8.38	11.92	5.88	11.21	1.32	11.27	1.86	9.59
15162.86f	.....	.....	.....	.....	2.38	11.02	....	.....	....	.....
15266.54f	.....	.....	.....	.....	7.58	11.69	....	.....	....	.....
15533.74f	.....	.....	.....	.....	18.73	10.72	....	.....	....	.....
15542.83f	.....	.....	2.62	10.86	8.12	11.58	2.86	11.78	0.62	9.04
15557.62f	0.80	10.94	4.51	11.54	3.22	11.21	0.86	11.06	0.73	8.89

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	Y Sct		Z Sct		RU Sct		X Sct		SS Sct	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
15558.68f	1.86	11.01	5.57	11.72	4.28	11.21	1.92	11.44	1.79	9.69
15561.67f	4.85	11.69	8.56	11.92	7.27	11.69	0.71	11.00	1.11	9.29
15571.71f	.....	.....	.....	.....	17.31	11.77	....	.....	....	.....
15602.56f	4.38	11.60	10.74	11.29	.....	.....	3.82	10.81	1.61	9.69
15631.56f	.....	.....	.....	.....	18.07	11.32	....	.....	....	.....
15635.56f	.....	.....	.....	.....	2.37	10.99	....	.....	....	.....
15872.85f	.....	.....	.....	.....	3.30	11.01	....	.....	....	.....
15898.73f	.....	.....	.....	.....	9.49	11.79	....	.....	....	.....
15903.83f	5.74	11.75	2.37	10.86	.....	.....	2.83	11.71	1.84	9.79
15912.74f	4.31	11.57	1.28	11.29	3.80	11.11	3.34	11.41	3.41	8.94
15934.74f	.....	.....	.....	.....	6.10	11.47	....	.....	....	.....
15971.56f	1.08	10.94	5.59	11.86	3.53	11.04	3.39	11.51	3.49	8.73
15993.54f	2.38	11.20	1.77	10.49	5.81	11.27	0.18	10.81	3.45	8.76
15995.61f	4.45	11.60	3.84	11.38	7.88	11.73	2.25	11.51	1.85	9.59
16033.52f	1.00	10.80	3.05	10.95	6.40	11.67	2.38	11.74	3.04	9.49
16226.81f	8.14	11.17	2.68	10.95	2.73	10.97	2.56	11.71	1.76	9.54
16230.81f	1.80	10.94	6.81	11.92	6.73	11.47	2.36	11.78	2.09	9.87
16241.77f	.....	.....	.....	.....	17.69	11.69	....	.....	....	.....
16253.76f	.....	.....	.....	.....	9.98	11.83	....	.....	....	.....
16284.84f	4.12	11.63	9.23	11.72	1.67	10.72	1.82	11.19	1.05	9.19
16292.77f	1.71	10.96	4.26	11.54	9.60	11.77	1.35	11.23	1.64	9.54
16310.64f	.....	.....	.....	.....	7.77	11.67	....	.....	....	.....
16312.76f	.....	.....	.....	.....	9.89	11.75	....	.....	3.27	9.04
16338.56f	6.14	11.75	11.35	11.12	15.99	11.73	0.96	11.00	3.38	8.99
16340.65f	8.23	11.23	0.53	10.22	18.08	11.21	3.05	11.51	1.79	9.87

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	Y Sct		Z Sct		RU Sct		X Sct		SS Sct	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
16361.58f	.....	.....	.....	.....	19.32	10.61	....	.....	....	.....
16376.58f	.....	.....	.....	.....	14.62	11.83	....	.....	....	.....
16583.83f	3.21	11.31	5.01	10.95	5.21	11.27	2.75	11.58	2.68	9.96
16593.84f	.....	.....	.....	.....	.....	.....	0.16	11.25	....	.....
16620.71f	.....	.....	.....	.....	2.70	10.83	....	.....	....	.....
16620.76f	9.12	10.99	9.71	11.72	2.75	11.06	1.90	11.25	2.89	9.45
16635.72f	3.40	11.51	11.77	10.77	17.71	11.71	....	.....	3.17	9.24
16636.81f	.....	.....	.....	.....	18.80	10.99	....	.....	....	.....
16639.71f	7.39	11.45	2.85	10.86	2.00	10.96	4.05	10.75	3.49	8.99
16649.74f	7.07	11.51	12.88	10.22	12.03	11.83	1.49	11.23	2.50	9.96
16652.80f	.....	.....	.....	.....	15.09	11.83	....	.....	....	.....
16663.75f	.....	.....	.....	.....	6.34	11.37	....	.....	....	.....
16669.79f	6.44	11.72	7.13	12.01	12.38	11.81	0.55	10.92	0.53	8.94
16697.63f	.....	.....	.....	.....	0.83	10.83	....	.....	....	.....
16711.53f	.....	.....	.....	.....	14.73	11.73	....	.....	....	.....
16753.53f	7.45	11.51	0.56	10.40	17.34	11.58	0.33	10.81	3.50	8.94
16766.51f	10.09	10.67	0.64	10.22	10.62	11.73	0.71	10.86	1.80	9.79
16943.89f	.....	.....	.....	.....	10.73	11.83	....	.....	....	.....
16975.72f	.....	.....	.....	.....	3.17	11.11	....	.....	....	.....
16976.79f	3.20	11.48	4.47	11.72	4.24	11.09	1.09	11.19	2.82	9.69
16991.81f	.....	.....	.....	.....	19.26	10.50	....	.....	....	.....
17000.83f	6.56	11.66	2.73	11.04	8.58	11.63	4.14	10.58	1.16	9.49
17004.70f	.....	.....	.....	.....	12.45	11.83	....	.....	....	.....
17010.69f	6.08	11.60	12.59	10.40	18.44	11.01	1.41	11.21	0.01	8.84
17018.67f	3.71	11.60	7.66	11.95	6.73	11.32	0.99	11.19	0.64	8.73

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and Telescope	Y Sct		Z Sct		RU Sct		X Sct		SS Sct	
	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
17032.73f	.....	.....	.....	.....	1.09	10.72	....	.....	....	.....
17049.67f	.....	.....	.....	.....	18.03	11.47	....	.....	....	.....
17053.58f	.....	.....	.....	.....	2.24	10.99	....	.....	....	.....
17053.72f	7.74	11.48	4.01	11.72	2.38	10.61	2.46	11.58	....	.....
17066.72f	0.06	10.55	4.11	11.38	15.38	11.77	2.86	11.78	0.97	8.99
17076.61f	9.95	10.67	1.10	10.59	5.58	11.42	0.16	11.04	3.52	8.89
17077.65f	0.65	10.80	1.94	10.77	6.62	11.67	1.20	11.19	0.89	9.09
17105.57f	.....	.....	.....	.....	14.84	11.77	....	.....	....	.....
17107.62f	9.93	10.80	6.30	11.80	16.89	11.65	1.78	11.23	1.49	9.64
17135.56f	6.85	11.66	8.44	11.86	5.44	11.21	0.34	10.92	0.06	8.67
17325.84f	0.64	10.67	5.19	11.72	18.45	11.08	1.71	11.38	3.11	9.29
17374.79f	8.23	11.15	2.54	10.68	8.31	11.67	0.28	10.81	0.66	8.99
17380.73f	3.83	11.60	8.48	11.83	14.25	11.73	2.02	11.31	2.93	9.59
17394.74f	7.49	11.57	9.58	11.54	8.56	11.73	3.44	11.41	2.25	9.87
17431.66f	3.05	11.25	7.80	12.10	6.09	11.42	2.58	11.71	2.46	9.87
17436.66f	8.05	11.17	12.80	10.13	11.09	11.73	3.38	11.44	0.12	8.64
17445.60f	6.65	11.75	8.84	11.89	0.33	10.61	3.92	10.81	1.72	9.87
17683.87f	7.07	11.45	1.98	10.68	2.25	10.94	2.91	11.64	1.36	9.49
17727.75f	9.58	10.99	7.15	11.89	6.73	11.53	0.61	10.81	1.19	9.59
17734.84f	6.33	11.75	1.34	10.40	13.82	11.77	3.50	11.44	0.93	9.14
17803.65f	2.75	11.17	5.64	11.95	3.85	11.21	0.94	11.15	0.00	8.67
17813.50f	2.26	11.10	2.59	10.86	13.70	11.79	2.40	11.64	2.50	9.87
17816.63f	5.39	11.69	5.72	11.80	16.83	11.71	1.33	11.23	1.96	9.79
18042.90f	4.15	11.54	12.66	10.22	6.74	11.58	0.90	11.08	0.61	8.94
18082.75f	2.63	11.20	0.90	10.68	7.20	11.53	2.97	11.58	0.08	8.73

TABLE IV.—Photographic Observations of Cepheid Variable Stars.—*Cont.*

Section A

J. D. and	Y Sct		Z Sct		RU Sct		X Sct		SS Sct	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
18097.85f	7.39	11.45	3.10	11.29	2.60	10.83	1.28	11.15	0.50	8.89
18110.78f	9.98	10.80	3.13	11.20	15.53	11.83	1.62	11.51	2.41	9.96
18132.66f	0.83	10.80	12.11	10.49	17.71	11.58	2.51	11.78	2.27	9.91
18155.69f	3.18	11.42	9.33	11.86	1.35	10.83	0.35	10.75	3.27	8.99
18158.53f	6.02	11.72	12.17	10.59	4.19	11.06	3.19	11.44	2.44	9.87
18158.58f	6.07	11.72	12.22	10.31	4.24	11.09	3.54	11.31	2.49	9.87
18202.61f	8.74	11.15	4.65	11.54	8.88	11.67	1.09	11.04	2.46	9.91
18427.84f	6.46	11.66	10.55	11.29	17.45	11.63	3.82	10.81	0.08	8.89
18441.75f	10.02	10.80	11.56	10.86	.....	.....	0.94	11.06	2.98	9.59
18467.80f	5.05	11.66	11.80	10.59	18.01	11.08	1.80	11.19	3.33	9.09
18477.80f	4.71	11.63	8.90	11.89	8.32	11.67	3.41	11.38	2.31	9.96
18533.55f	8.75	11.15	0.14	10.22	4.98	11.08	0.39	10.86	3.00	9.29
18534.63f	9.83	10.94	1.22	10.31	6.06	11.27	1.47	11.25	0.41	8.94
18539.64f	4.50	11.75	6.23	11.80	11.07	11.77	2.28	11.58	1.74	9.59
18541.50f	6.36	11.69	8.09	12.10	12.93	11.77	4.14	10.70	3.60	8.67
18561.56f	5.74	11.69	2.35	10.86	13.29	11.69	3.21	11.38	1.64	9.64
18569.55f	3.39	11.54	10.34	11.12	1.59	10.72	2.80	11.64	2.29	9.87
18574.53f	7.49	11.51	2.42	10.86	6.57	11.42	3.58	11.23	3.59	8.67
18821.84f	7.48	11.45	4.59	11.54	17.52	11.63	3.21	11.64	1.26	9.49
18834.83f	10.13	10.80	4.68	11.63	10.81	11.83	3.61	11.23	3.24	9.49
18849.76f	4.38	11.63	6.71	11.80	6.05	11.47	1.74	11.23	3.49	8.73
18864.76f	9.04	11.12	8.81	11.83	1.35	10.72	4.15	10.70	0.13	8.73
18870.70f	4.64	11.69	1.85	10.59	7.29	11.63	1.69	11.27	2.40	9.96
18911.62f	4.19	11.69	4.06	11.46	8.82	11.67	0.63	11.00	2.93	9.69
18918.57f	0.80	10.80	11.01	10.95	.....	.....	3.39	11.31	2.54	9.96

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	Y Sct		Z Sct		RU Sct		X Sct		SS Sct	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
19234.73f	6.72	11.60	4.63	11.54	16.78	11.73	0.50	10.81	2.98	9.59
19290.59f	0.53	10.67	8.88	11.89	.....	.....	1.78	11.27	0.10	8.61
19310.52f	0.12	10.55	3.01	11.29	13.79	11.75	0.72	11.19	1.68	9.87
19566.71f	.....	.....	0.16	10.49	.....	.....	0.83	11.15	0.88	9.19
19603.70f	.....	.....	12.35	10.40	.....	.....	0.04	10.70	1.16	9.59
19606.64f	6.34	11.72	2.39	10.86	14.46	11.75	2.98	11.64	0.43	8.73
19616.67f	6.02	11.75	2.42	10.68	4.79	11.11	0.42	10.81	3.12	9.49
19631.62f	0.29	10.80	1.57	10.68	0.05	10.50	....	.....	3.38	8.99
19916.84f	.....	.....	2.95	11.20	.....	.....	2.53	11.85	2.25	9.96
19921.84f	0.95	10.94	7.95	11.89	.....	.....	3.33	11.71	3.58	8.79
19933.82f	2.59	11.20	7.03	11.86	6.80	11.32	2.71	11.98	0.87	9.09
19942.81f	1.24	11.01	3.11	11.29	17.79	11.65	3.31	11.78	2.52	9.87
19972.75f	0.16	10.67	7.25	12.01	6.34	11.63	3.86	10.81	3.09	9.69
20069.52f	.....	.....	0.81	10.68	.....	.....	4.08	10.81	0.74	9.14
20341.69f	7.15	11.60	2.04	10.86	1.04	10.83	3.37	11.38	1.24	9.69
20357.64f	.....	.....	5.09	11.72	.....	.....	2.53	11.58	2.51	9.79
20361.62f	6.39	11.69	.....	.....	1.28	10.83	2.31	11.85	2.82	9.87
20363.54f	8.31	11.12	10.99	11.12	3.20	11.06	0.04	10.58	1.07	9.39
20387.58f	1.33	10.96	9.23	11.80	7.54	11.58	3.09	11.71	3.08	9.59
20391.57f	5.32	11.72	0.31	10.22	11.53	11.83	2.88	11.64	3.40	8.76
20398.58f	1.99	11.17	7.32	11.86	18.54	10.94	1.49	11.31	3.07	9.59
20444.63f	6.67	11.69	1.77	10.49	5.50	11.21	1.36	11.19	1.39	9.59
20670.66f	5.19	11.75	8.47	11.92	14.87	11.83	0.70	10.81	3.48	8.94
20682.77f	6.96	11.57	.....	.....	.....	.....	0.22	10.81	0.90	9.09
20691.73f	.....	.....	3.73	11.72	.....	.....	0.78	11.04	....	.....

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	Y Sct		Z Sct		RU Sct		X Sct		SS Sct	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
20708.63f	1.80	11.01	7.73	11.95	.....	.....	0.89	11.04	1.06	9.19
20719.61f	.....	.....	5.81	11.89	4.73	11.21	3.47	11.27	1.03	9.19
20752.49f	4.29	11.75	12.89	10.22	17.91	11.32	2.77	11.78	0.87	9.14
21023.74f	6.67	11.78	0.30	10.22	.....	.....	1.15	11.15	0.45	8.73
21038.67f	0.91	10.96	2.33	11.04	.....	.....	3.48	11.27	0.70	9.09
21047.76f	10.00	10.94	11.42	11.12	.....	.....	4.18	10.70	2.45	9.96
21062.68f	.....	.....	0.53	10.49	12.96	11.77	2.30	11.71	2.68	9.87
21064.67f	6.23	11.81	2.52	10.77	14.95	11.83	0.10	10.75	1.00	9.29
21066.68f	8.24	11.10	4.53	11.72	16.96	11.63	2.11	11.71	3.01	9.79
21069.68f	0.90	10.67	7.53	12.04	0.26	10.50	0.91	11.12	2.34	9.87
21073.63f	4.85	11.75	11.48	11.12	4.21	11.27	0.66	11.00	2.62	9.79
21079.59f	0.47	10.67	4.54	11.54	10.17	11.79	2.42	11.58	1.24	9.29
21080.60f	1.48	11.01	5.55	11.80	11.18	11.79	3.43	11.27	2.25	9.87
21092.54f	3.08	11.48	4.59	11.63	3.43	11.08	2.78	11.58	3.17	9.39
21098.58f	9.12	11.12	10.63	11.20	9.47	11.67	0.42	10.81	1.87	9.87
21099.55f	10.09	10.67	11.60	10.77	10.44	11.79	1.39	11.23	2.84	9.79
21101.56f	.....	.....	0.71	10.68	.....	.....	3.40	11.27	1.18	9.59
21103.55f	3.74	11.54	2.70	11.20	14.44	11.79	1.19	11.12	3.17	9.49
21155.49f	3.98	11.54	3.03	11.20	7.29	11.73	2.76	11.85	0.04	8.79
21393.75f	.....	.....	9.06	11.89	9.19	11.73	1.73	11.38	3.34	8.99
21398.74f	9.38	11.06	1.15	10.59	.....	.....	2.52	11.71	0.99	9.09
21399.72f	0.01	10.67	2.13	10.86	.....	.....	3.50	11.27	1.97	9.96
21425.67f	.....	.....	2.28	10.86	.....	.....	0.07	10.81	2.22	9.87
21428.66f	8.27	11.25	5.27	11.86	.....	.....	3.06	11.78	1.54	9.49
21438.67f	.....	.....	2.37	10.95	14.72	11.83	0.47	11.08	0.54	8.99

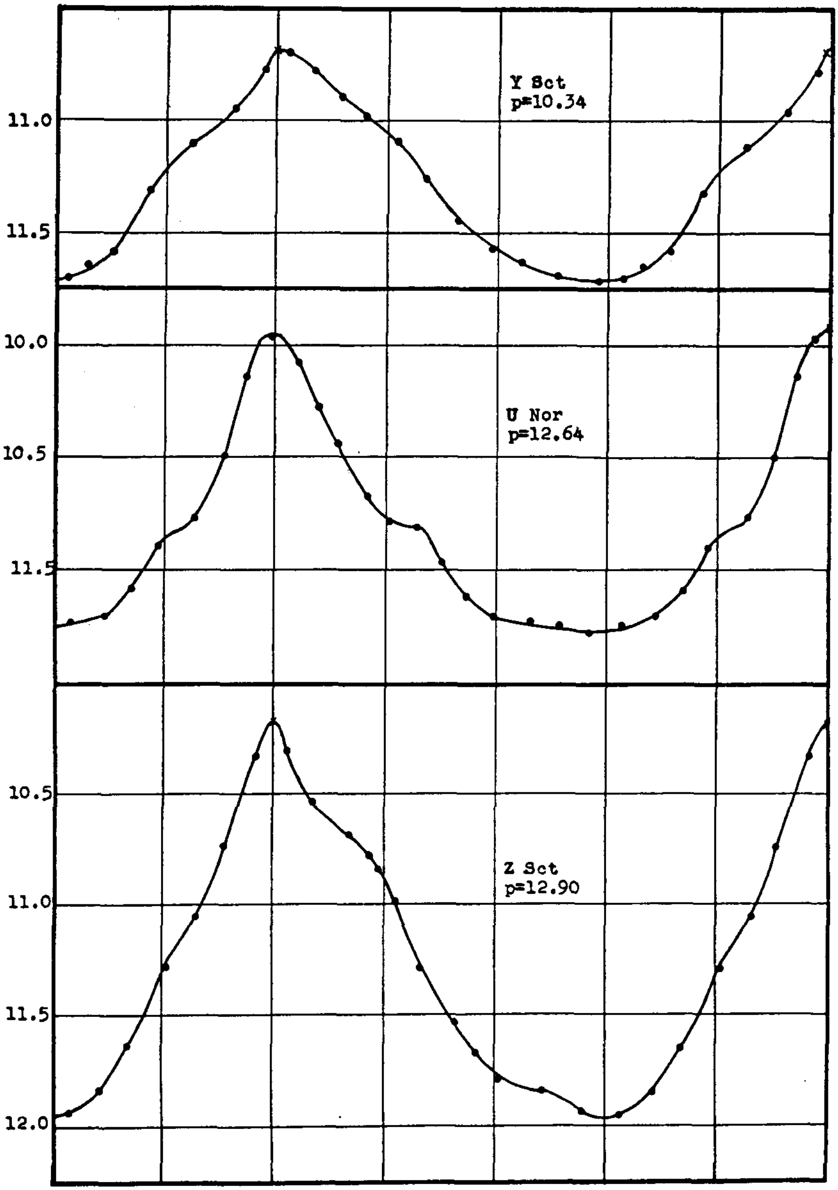

11.0
11.5
Y Sct
p=10.34
10.0
10.5
11.5
U Nor
p=12.64
10.5
11.0
11.5
12.0
Z Sct
p=12.90

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	Y Sct		Z Sct		RU Sct		X Sct		SS Sct	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
21451.58f	0.17	10.67	2.38	10.86	7.93	11.71	0.79	11.00	2.44	10.04
21454.62f	3.21	11.45	5.42	11.89	10.97	11.77	3.83	11.29	1.80	9.69
21455.56f	4.15	11.63	6.36	11.89	11.91	11.79	0.57	11.15	2.74	9.87
21460.55f	9.14	11.10	11.35	10.77	16.90	11.79	1.36	11.23	....	.....
21460.60f	.....	.....	11.40	11.29	16.95	11.81	1.41	11.27	0.44	8.89
21462.52f	0.77	10.94	0.42	10.31	18.87	10.83	3.33	11.64	2.36	10.04
21523.54f	10.08	10.67	9.83	11.54	1.11	10.72	1.38	11.23	0.97	9.09
21758.72f	7.41	11.54	12.78	10.13	19.62	10.39	1.47	11.38	1.20	9.69
21788.68f	6.34	11.69	4.04	11.63	.....	.....	2.05	11.71	1.79	9.91
21790.67f	8.33	11.23	6.03	11.80	.....	.....	4.04	10.81	0.11	8.73
21817.56f	4.20	11.57	7.11	11.89	19.38	10.22	1.54	11.23	1.30	9.69
21818.58f	5.22	11.66	8.13	11.95	0.70	10.83	2.56	11.58	2.32	10.04
21819.55f	6.19	11.69	9.10	11.72	1.67	11.01	3.53	11.27	3.29	9.19
21834.58f	0.54	10.80	11.23	11.77	16.70	11.47	....	.....	3.63	8.99
21836.53f	2.49	11.20	0.28	10.22	18.65	10.97	3.72	11.23	1.91	9.96
21844.56f	0.17	10.67	.....	.....	.....	.....	3.35	11.71	2.60	9.79
21847.54f	3.15	11.60	11.29	11.20	.....	.....	2.13	11.64	1.91	9.87
22135.67f	1.73	11.01	2.68	11.12	2.65	10.83	0.60	11.08	0.01	8.79
22194.56f	8.91	11.01	9.96	11.63	2.45	10.99	0.72	10.98	0.17	8.89
22543.60f	6.34	11.63	10.66	11.54	16.65	11.67	1.32	11.23	0.44	9.09
22546.65f	9.39	11.10	0.81	10.59	0.00	10.17	0.17	11.04	3.49	8.99
22584.56f	5.94	11.75	0.01	9.94	18.21	11.21	0.30	10.70	1.02	9.49
23181.86f	3.43	11.54	3.83	11.29	4.93	11.42	1.48	11.44	3.59	8.79
23198.82f	10.05	10.80	7.89	11.89	2.19	10.97	1.65	11.27	2.19	9.87
23205.79f	6.68	11.66	1.96	10.77	9.16	11.75	0.22	10.81	1.82	9.91

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	Y Sct		Z Sct		RU Sct		X Sct		SS Sct	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
23219.72f	10.27	10.55	2.99	10.95	3.39	11.06	1.56	11.44	1.06	9.19
23225.75f	.....	.....	9.02	11.72	9.42	11.83	3.39	11.44	3.42	9.29
23234.74f	4.61	11.63	5.10	11.83	18.41	10.94	3.98	10.81	....	.....
23248.68f	.....	.....	6.14	11.83	12.65	11.83	1.13	11.19	0.66	8.89
23257.65f	6.84	11.69	2.21	10.86	1.93	10.97	1.71	11.31	2.28	10.04
23305.62f	3.10	11.28	1.48	10.86	10.50	11.69	3.50	11.51	2.53	9.87
23314.60f	1.74	10.99	7.55	11.98	19.48	10.50	4.08	10.81	0.49	9.04
23338.57f	.....	.....	5.72	11.89	4.06	11.16	2.86	11.58	2.44	9.87
23535.87f	5.84	11.69	9.49	11.46	4.40	11.11	2.86	11.71	1.50	9.87
23641.68f	8.23	11.23	12.09	10.68	11.72	11.83	3.72	11.19	0.84	9.09
23666.56f	2.09	10.96	11.17	10.86	16.91	11.79	3.41	11.27	0.02	8.79
23691.53f	6.38	11.75	10.33	11.20	.....	.....	3.19	11.78	2.96	9.69
23695.55z	0.06	10.80	1.45	10.68	6.50	11.42	3.01	11.78	3.31	9.19
23698.52z	3.03	11.20	4.42	11.54	9.47	11.71	1.78	11.23	2.61	9.69
23702.53z	....	.....	8.43	11.98	13.48	11.83	1.60	11.23	2.95	9.87
23914.87z	2.21	11.12	1.44	10.77	9.17	11.83	4.03	10.70	2.36	9.87
23931.77y	8.76	11.01	5.44	11.92	6.37	11.58	4.14	10.58	0.90	9.09
23934.77z	1.42	10.94	8.44	11.98	9.37	11.79	2.94	11.58	0.23	8.79
23935.78z	2.43	11.12	9.45	11.92	10.37	11.77	3.95	10.92	1.24	9.49
23936.77y	3.42	11.51	10.44	10.95	11.37	11.83	0.75	11.04	2.23	9.96
23939.78z	6.43	11.75	0.55	10.59	14.38	11.83	3.76	11.08	1.57	9.87
23962.72z	.....	.....	10.59	11.63	17.62	11.63	1.51	11.27	2.49	9.79
24018.61z	2.53	11.15	1.97	10.68	14.42	11.89	2.82	11.71	3.31	8.99
24025.57y	9.49	11.01	8.93	11.80	1.68	10.83	1.39	11.23	2.93	9.87
24047.57z	0.47	10.80	5.13	11.80	3.99	11.27	2.40	11.78	2.90	9.44

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION A

J. D. and	Y Sct		Z Sct		RU Sct		X Sct		SS Sct	
Telescope	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
24073.53z	5.75	11.75	5.28	11.80	10.25	11.69	3.17	11.78	3.16	9.39
24089.47y	1.00	10.80	.....	.....	6.50	11.27	2.32	11.51	0.74	8.99
24289.86z	4.91	11.57	2.28	10.68	9.92	11.69	1.20	11.00	2.89	9.39
24328.76z	2.44	11.08	2.48	10.86	9.43	11.69	2.32	11.51	.....	....
24346.64z	9.98	10.96	7.46	12.01	7.61	11.63	3.41	11.38	0.93	9.19
24346.69y	10.03	10.80	.....	.....	7.66	11.63	3.46	11.58	0.98	8.99
24401.58z	2.87	11.15	10.79	10.86	3.46	10.99	3.77	10.81	0.80	9.09
24415.51y	6.46	11.63	11.82	10.49	17.39	11.53	0.91	11.23	0.05	8.79
24627.86z	1.64	10.94	4.84	11.80	13.08	11.83	3.36	11.27	3.14	9.09
24682.74z	5.81	11.63	8.11	11.98	8.87	11.63	3.67	11.23	2.95	9.64
24699.69z	1.08	10.96	12.16	10.31	6.12	11.47	3.82	11.04	1.55	9.59
24740.54z	0.56	10.67	1.40	10.31	7.58	11.58	2.69	11.71	.....	....
24767.57y	6.91	11.57	2.63	10.86	14.92	11.77	0.34	10.81	3.35	9.19
24769.53y	8.87	11.08	4.59	11.63	16.88	11.73	2.30	11.51	1.63	9.87
24999.82y	1.31	11.01	2.65	10.77	10.81	11.73	1.70	11.44	0.64	8.89
25108.61y	6.69	11.51	8.22	12.07	1.42	10.72	1.34	11.19	2.97	9.59
25122.53y	10.26	10.80	.....	.....	.....	.....	....	.....	....	.....
25388.50z	7.36	11.54	4.28	11.54	5.56	11.47	4.16	10.70	0.17	8.73
25413.76r	1.59	11.01	3.73	11.38	.....	.....	0.03	10.70	....	.....
25449.67r	6.48	11.66	0.94	10.22	.....	.....	2.36	11.51	2.61	9.69
25801.70r	6.90	11.48	4.62	11.54	5.13	11.06	1.75	11.19	....	.....
25808.72r	3.58	11.48	11.64	10.68	12.15	11.77	0.38	10.81	1.88	9.87
25824.64r	9.16	11.01	1.76	10.86	8.38	11.53	3.70	11.23	3.11	9.49
25878.52r	0.99	10.80	4.03	11.54	.....	.....	3.01	11.44	1.93	9.87
25889.51r	1.64	10.99	2.12	10.77	.....	.....	1.40	11.04	1.90	9.87

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and Telescope	W Sgr		X Sgr	
	Phase	Mag.	Phase	Mag.
14757.84e	0.80	5.00	3.87	5.91
14767.81e	3.18	5.64	6.83	5.16
14812.70e	2.50	5.64	2.64	5.80
14862.62f	6.85	5.48	3.49	5.96
14867.61f	4.24	6.03	1.47	5.64
14874.59f	3.63	5.48	1.43	5.85
14875.60f	4.64	6.03	2.44	5.64
14898.57f	4.82	6.15	4.38	5.91
14904.57f	3.23	6.03	3.37	6.07
14935.52f	3.80	5.64	6.28	5.64
14942.53f	3.21	5.48	6.27	4.84
15071.88f	3.45	5.92	2.41	5.48
15091.91e	0.69	4.84	1.41	5.32
15117.82f	3.82	5.80	6.29	5.00
15119.82e	5.82	6.15	1.27	5.32
15148.72f	4.34	6.26	2.13	5.32
15192.65e	2.70	5.64	3.99	5.32
15198.67f	1.12	5.16	3.00	5.91
15223.64e	5.71	6.50	2.92	5.64
15264.56f	6.25	6.09	5.79	5.32
15465.91e	2.54	5.48	....	....
15517.75e	1.22	5.32	6.58	5.16
15526.86f	2.73	5.64	1.67	5.32
15532.70f	0.98	5.32	0.50	5.16
15533.69f	1.97	5 64	1.49	5.32
15540.69e	1.37	5.32	1.47	5.32
15560.67f	6.16	5.80	0.42	4.84
15575.67f	5.97	6.32	1.40	5.48
15602.60f	2.52	5.48	0.28	5.48
15609.60f	1.93	5.16	0.27	5.32
15609.64f	1.97	5.32	0.31	5.00
15613.57e	5.90	6.38	4.24	6.02
15632.57f	2.11	5.32	2.21	5.85
15634.52e	4.06	6.38	4.16	5.80
15634.57f	4.11	6.26	4.21	6.07
15636.51e	6.03	6.03	6.15	5.16
15841.89f	3.84	5.80	1.20	5.48
15842.81f	7.29	4.84	2.12	5.91
15842.87e	7.35	5.00	2.18	5.32
15868.78f	2.88	5.48	0.04	5.16
15870.75f	4.85	6.03	2.01	5.64
15872.81f	....	....	4.07	6.18
15873.81e	0.31	5.00	5.07	5.48
15885.83f	4.74	6.38	3.07	6.07
15896.73e	0.45	5.32	6.96	4.52
15897.70f	1.42	5.48	0.92	5.16
15898.73e	2.45	5.32	1.95	5.32
15911.72f	0.15	5.00	0.91	5.32

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and Telescope	W Sgr		X Sgr	
	Phase	Mag.	Phase	Mag.
15912.61f	1.14	4.84	1.80	5.32
15914.54f	3.07	5.48	3.73	6.02
15914.59f	3.12	5.48	3.78	5.96
15918.73f	7.26	5.16	0.91	5.16
15925.70f	6.63	5.64	0.87	4.84
15927.63f	0.97	5.16	2.80	5.96
15927.67f	1.01	5.00	2.84	5.64
15932.65e	5.99	5.92	0.81	5.32
15933.68f	7.02	5.48	1.84	5.80
15934.65f	0.39	5.32	2.81	6.02
15938.66f	4.40	6.50	6.81	4.68
15940.64f	6.38	6.20	1.79	5.64
15943.62e	1.77	5.32	4.77	5.64
15960.65f	3.61	6.15	0.77	4.68
15974.57f	2.34	5.32	0.66	4.84
16006.60f	3.99	6.38	4.65	5.96
16010.57f	0.37	5.16	1.61	5.32
16023.56f	5.76	6.38	0.58	5.32
16034.52f	1.53	5.48	4.52	5.64
16177.84f	0.54	4.84	0.61	5.00
16208.77f	1.09	5.00	3.50	5.85
16222.70f	7.43	4.68	3.40	5.85
16224.86e	1.99	5.16	5.56	5.00
16226.76f	3.89	5.80	0.45	4.68
16226.82e	3.95	6.15	0.51	4.68
16229.77f	6.90	5.48	3.46	5.85
16232.77e	2.31	5.32	6.46	4.68
16233.78f	3.32	5.92	0.46	5.00
16235.77e	5.31	6.26	2.45	5.16
16241.73f	3.67	6.26	1.40	5.16
16253.71f	0.46	5.32	6.37	5.00
16254.82f	1.57	5.24	0.47	4.84
16257.73e	4.48	6.03	3.38	5.91
16259.72e	6.47	6.03	5.37	5.64
16260.73e	7.48	5.00	6.38	5.00
16268.68f	0.24	4.68	0.30	5.00
16268.73f	0.29	4.84	0.35	5.00
16279.75f	3.72	5.64	4.36	5.85
16279.80f	3.77	5.92	4.41	5.64
16282.66e	6.63	5.48	0.26	5.00
16284.79f	1.16	5.00	2.39	5.32
16288.73f	5.10	6.09	6.33	5.32
16295.58f	4.36	5.92	6.17	5.32
16297.69f	6.47	6.15	1.27	5.16
16308.64f	2.23	5.40	5.21	5.80
16311.63f	5.22	6.50	1.19	5.16
16320.57e	6.56	5.48	3.12	5.80
16337.61f	0.82	5.32	6.13	5.32

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

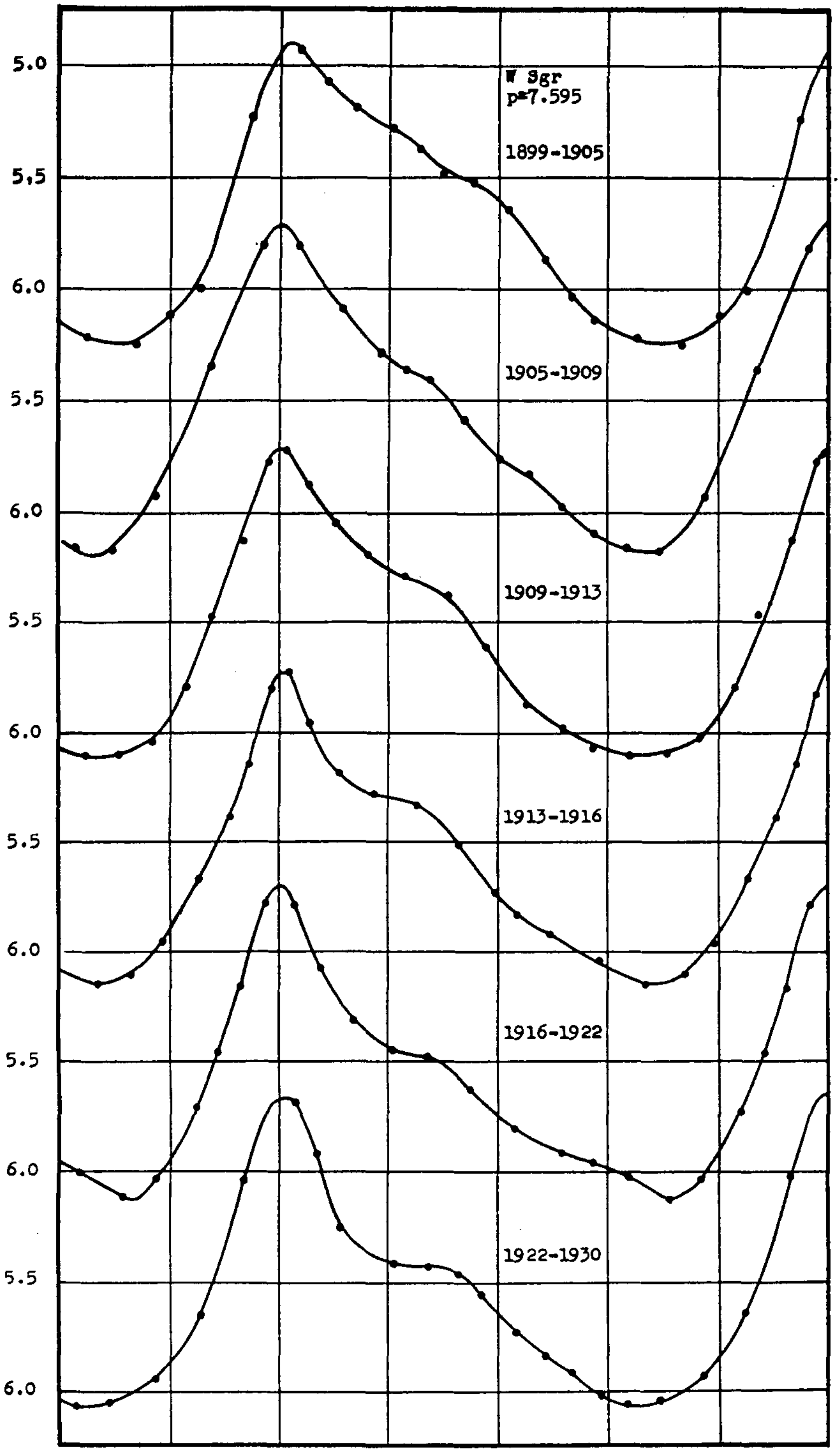
SECTION B

J. D. and	W Sgr		X Sgr		J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Telescope	Phase	Mag.	Phase	Mag.
16337.65f	0.86	5.32	6.17	5.40	16644.68e	4.09	5.92	4.71	5.80
16339.61f	2.82	5.32	1.12	5.48	16646.70f	6.11	6.38	6.73	5.00
16339.65f	2.86	5.80	1.16	5.64	16650.72f	2.53	5.80	3.74	6.18
16344.64f	0.25	4.68	6.15	5.64	16650.76f	2.57	5.48	3.78	5.96
16361.62f	2.04	5.48	2.10	5.32	16652.62f	4.43	6.03	5.64	5.64
16376.62f	1.85	5.64	3.08	5.96	16663.60e	0.22	5.16	2.60	4.68
16396.54f	6.58	5.72	1.96	5.48	16663.80f	0.42	5.00	2.80	5.96
16553.90e	4.45	6.03	5.08	5.48	16668.72f	5.34	6.03	0.71	5.00
16582.72f	2.89	5.48	5.85	5.00	16669.70f	6.33	6.03	1.69	5.80
16582.77f	2.94	5.32	5.90	5.64	16683.52f	4.95	6.26	1.49	5.16
16583.88e	4.05	6.03	0.00	4.68	16691.57e	5.41	6.15	2.53	5.48
16585.75f	5.92	6.03	1.87	5.48	16691.57f	5.41	5.92	2.53	5.64
16591.71f	4.28	5.92	0.82	5.48	16694.63f	0.87	5.00	5.59	5.48
16606.72f	4.10	6.15	1.81	5.48	16694.67f	0.91	5.00	5.63	5.64
16606.80f	4.18	6.03	1.89	5.16	16697.67f	2.63	6.26	1.50	5.48
16608.80f	6.18	5.92	3.89	5.96	16711.58f	2.41	5.16	2.45	5.16
16608.87f	6.25	6.15	3.96	5.96	16726.55f	4.21	5.48	5.42	5.96
16613.75e	3.54	5.64	1.83	5.48	16743.54f	5.23	5.92	6.44	5.48
16615.72f	5.51	6.15	3.80	5.91	16760.51f	5.99	5.92	1.35	5.64
16634.63f	1.63	5.64	1.67	5.64	16922.89f	1.29	5.48	2.48	5.48
16634.67f	1.67	5.32	1.71	5.48	16933.84f	4.64	6.15	6.42	5.32
16636.77f	3.77	6.26	3.81	6.07	16934.87f	5.67	5.80	0.44	5.32
16640.76f	0.17	5.32	0.79	5.32	16935.79f	6.59	5.72	1.36	5.00
16642.68e	2.09	5.48	2.71	5.80	16938.79f	2.00	5.56	4.36	5.80

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and	W Sgr		X Sgr		J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Telescope	Phase	Mag.	Phase	Mag.
16938.83f	2.04	5.16	4.40	5.91	17066.58f	0.67	5.00	5.94	5.64
16939.85e	3.06	5.48	5.42	5.32	17075.57f	2.07	5.16	0.91	5.48
16943.84f	7.05	5.92	2.39	5.32	17076.67f	3.17	6.15	2.01	5.91
16944.86e	0.47	4.68	3.41	5.85	17098.57f	2.28	5.48	2.88	5.85
16968.80f	1.63	5.16	6.32	5.00	17105.61f	1.73	5.48	2.91	5.96
16976.70f	1.93	5.48	0.20	5.48	17107.57f	3.69	5.92	4.87	6.02
16976.75f	1.98	5.16	0.25	5.00	17124.53f	5.46	5.92	0.79	5.16
16979.77f	5.00	6.38	3.27	5.96	17319.82e	3.28	5.64	6.78	5.16
16988.79f	6.43	5.64	5.28	5.85	17325.76f	1.62	5.48	5.71	5.64
16989.73e	7.37	5.00	6.22	5.00	17325.80f	1.66	5.16	5.75	5.91
16991.77f	1.89	5.32	1.25	5.64	17335.80f	4.07	6.26	1.73	5.85
16999.64f	2.09	5.64	2.10	5.85	17343.82f	4.49	5.80	2.94	5.85
16999.69f	2.14	5.32	2.15	5.85	17353.83f	6.91	5.64	5.74	5.85
17004.65f	7.10	5.64	0.10	4.84	17360.74f	6.22	6.26	5.64	5.91
17006.72f	1.57	5.64	2.17	5.80	17363.78f	1.67	5.48	1.66	5.64
17007.65f	2.50	5.64	3.10	5.80	17371.74f	2.03	5.48	2.61	5.85
17009.77f	4.62	6.50	5.22	5.96	17372.67e	2.96	5.64	3.64	5.92
17017.76f	5.02	6.03	6.20	5.32	17375.69e	5.98	5.48	6.56	5.00
17019.77f	....	....	1.20	4.84	17376.72f	7.01	5.32	0.58	5.32
17025.68e	5.34	6.03	0.10	4.68	17377.70f	0.40	4.68	1.56	5.85
17031.70e	3.77	5.80	6.12	5.16	17378.71f	1.41	5.16	2.57	5.56
17032.77f	4.84	6.38	0.18	5.16	17384.72f	7.42	5.16	1.57	5.64
17034.63e	6.70	5.32	2.04	5.48	17394.61f	2.12	5.16	4.45	5.32
17037.67f	2.14	5.80	5.08	5.80	17394.70f	2.21	5.64	4.54	6.12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W Sgr
p=7.595
1899-1905
1905-1909
1909-1913
1913-1916
1916-1922
1922-1930

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and	W Sgr		X Sgr		J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Telescope	Phase	Mag.	Phase	Mag.
17403.63f	3.54	5.64	6.46	5.48	17706.82f	2.93	5.92	1.16	5.16
17403.72f	3.63	6.15	6.55	5.00	17707.81q	3.92	5.80	2.15	5.48
17408.62e	0.94	5.16	4.44	5.80	17718.77f	7.29	4.76	6.10	5.48
17429.62f	6.75	5.48	4.40	5.96	17727.71f	1.04	5.32	1.01	5.32
17430.57f	0.10	4.52	5.35	5.96	17728.80f	2.13	5.16	2.10	5.48
17431.57f	1.10	5.16	6.35	5.85	17730.74f	4.07	6.03	4.04	5.96
17433.63f	3.16	5.64	1.40	5.64	17758.68f	1.63	5.48	3.94	5.91
17437.56e	7.09	5.32	5.33	5.80	17758.72f	1.67	5.48	3.98	5.91
17445.55f	7.49	4.52	6.31	5.85	17759.67f	2.62	5.64	4.93	5.91
17447.57f	1.91	5.32	1.32	5.80	17762.63e	5.58	6.26	0.88	5.48
17450.55f	4.89	6.38	4.30	6.07	17774.72f	2.48	5.92	5.96	5.91
17454.53e	1.28	5.32	1.27	5.16	17784.62e	4.78	6.15	1.84	5.48
17458.57q	5.32	5.92	5.31	5.85	17787.64f	0.21	5.16	4.86	6.02
17459.57q	6.32	5.48	6.31	5.64	17789.65f	2.22	5.32	6.87	5.00
17465.56f	4.71	6.38	5.29	6.07	17793.63f	6.20	6.03	3.83	5.93
17476.51f	0.47	4.84	2.22	5.91	17797.56e	2.53	5.64	0.75	5.00
17482.52f	6.48	5.64	1.22	5.80	17802.55f	7.52	4.76	5.74	5.91
17492.49q	1.26	5.48	4.17	5.80	17803.55e	0.93	5.32	6.74	5.32
17493.51f	2.28	5.32	5.19	5.96	17803.56f	0.94	4.84	6.75	4.68
17495.54f	4.31	6.38	0.21	5.00	17813.55f	3.33	6.15	2.72	6.02
17680.84q	7.33	4.92	3.22	5.80	17816.55f	6.33	6.03	5.72	5.80
17684.80f	3.70	5.92	0.17	5.00	17820.55f	2.74	5.92	2.71	5.96
17686.81f	5.71	6.03	2.18	5.91	17858.48q	2.69	5.32	5.58	5.80
17703.90f	0.01	5.00	5.25	6.02	18027.89f	5.01	6.26	6.73	5.16

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and	W Sgr		X Sgr		J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Telescope	Phase	Mag.	Phase	Mag.
18033.85f	3.38	5.64	5.68	5.96	18145.61f	1.21	5.32	5.26	5.91
18034.81f	4.34	5.80	6.64	5.32	18148.66f	4.26	6.15	1.30	5.16
18034.83e	4.36	5.92	6.66	5.00	18149.59f	5.19	6.15	2.23	5.64
18042.86f	4.79	6.26	0.66	5.16	18155.60f	3.61	5.80	1.22	5.48
18045.86q	0.20	4.68	3.66	5.72	18156.61f	4.62	6.38	2.23	5.91
18056.75f	3.49	5.64	0.53	5.16	18157.56f	5.57	6.20	3.18	5.80
18063.79e	2.94	5.48	0.56	5.48	18169.56f	2.38	5.48	1.16	5.40
18069.81f	1.37	5.16	6.58	5.40	18171.52f	4.34	5.80	3.12	6.02
18069.86f	1.42	5.32	6.63	5.32	18174.57f	7.39	4.52	6.17	5.16
18070.74f	2.30	5.16	0.50	5.24	18174.65q	7.47	5.16	6.25	5.64
18087.76q	4.12	6.03	3.50	5.80	18182.59q	0.22	4.76	0.17	5.00
18097.77f	6.54	5.56	6.49	5.32	18183.52f	1.15	5.32	1.10	5.32
18098.80f	7.57	4.68	0.51	5.32	18193.51e	3.54	5.64	4.08	5.80
18100.72f	1.89	5.48	2.43	5.48	18194.53q	4.56	5.86	5.10	5.64
18103.70e	4.87	6.15	5.41	5.72	18197.58f	0.02	5.00	1.14	5.48
18111.72f	5.30	6.26	6.42	5.32	18199.56f	2.00	5.32	3.12	6.02
18111.78f	5.36	6.26	6.48	5.32	18200.52q	2.96	5.80	4.08	5.72
18119.58f	5.56	6.15	0.26	4.84	18209.53f	4.37	6.26	6.08	5.64
18119.73q	5.71	5.92	0.41	4.55	18395.85f	0.82	5.00	3.10	6.07
18123.68e	2.07	5.32	4.36	5.80	18404.87f	2.25	5.32	5.10	5.85
18129.66e	0.45	4.84	3.33	5.80	18420.75f	2.94	5.48	6.96	4.84
18129.67f	0.46	5.16	3.34	5.80	18421.81e	4.00	6.03	1.01	5.16
18130.68f	1.47	5.48	4.35	6.07	18421.85q	4.04	5.92	1.05	5.16
18138.65q	1.75	5.32	5.31	5.80	18422.75f	4.94	6.15	1.95	5.48

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and	W Sgr		X Sgr		J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Telescope	Phase	Mag.	Phase	Mag.
18423.81e	6.00	6.03	3.01	5.80	18500.72f	6.96	5.48	2.80	5.96
18436.82f	3.82	5.92	2.00	5.48	18501.59f	0.23	5.00	3.67	6.07
18439.79q	6.79	5.64	4.97	5.91	18501.64f	0.28	4.68	3.72	5.80
18440.69f	0.09	4.68	5.87	5.91	18505.66f	4.30	6.15	0.73	5.32
18452.71q	4.52	6.38	3.87	5.72	18506.68f	5.32	6.38	1.75	5.80
18453.80f	5.61	6.38	4.96	6.12	18507.60e	6.24	5.64	2.67	5.32
18454.78f	6.59	5.32	5.94	5.48	18510.60f	1.65	5.40	5.67	5.80
18457.67f	1.88	5.48	1.81	5.64	18511.60f	2.65	5.32	6.67	4.68
18466.70e	3.32	5.64	3.83	6.03	18513.52f	4.57	6.15	1.58	5.48
18466.73f	3.35	6.03	3.86	6.03	18514.62f	5.67	5.92	2.68	5.85
18466.75q	3.37	5.80	3.88	5.72	18514.63q	5.68	6.15	2.69	5.48
18467.71f	4.33	6.38	4.84	6.15	18516.60f	0.05	4.68	4.66	6.07
18471.75f	0.77	4.84	1.87	5.32	18521.61q	5.06	5.92	2.65	5.48
18472.69f	1.71	5.32	2.81	5.64	18523.61f	7.06	5.24	4.65	5.91
18473.74q	2.76	5.72	3.86	5.72	18530.62f	6.48	6.03	4.65	6.07
18474.70e	3.72	5.64	4.82	6.02	18531.56f	7.42	4.52	5.59	5.96
18475.73f	4.75	6.20	5.85	5.91	18531.61f	7.47	5.00	5.64	6.02
18479.65f	1.08	4.92	2.76	5.91	18535.56f	3.82	5.80	2.58	5.48
18481.68f	3.11	5.92	4.79	5.96	18537.55f	5.81	6.03	4.57	5.91
18483.60f	5.03	6.09	6.71	4.84	18547.59q	0.66	4.68	0.59	5.00
18484.72q	6.15	6.03	0.82	4.84	18562.50f	0.38	4.68	1.48	5.48
18495.69f	1.93	5.32	4.78	5.91	18565.53f	3.41	6.15	4.51	6.18
18497.68q	3.92	5.92	6.78	4.52	18671.52f	3.07	5.80	5.33	6.07
18499.71f	5.95	6.26	1.79	5.32	18752.84e	0.85	5.32	2.52	5.32

TABLE IV.—Photographic Observations of Cepheid Variable Stars.—*Cont.*

Section B

J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.
18752.89q	0.90	5.48	2.57	5.48
18766.84f	7.25	4.68	2.49	5.64
18774.85e	0.07	5.00	3.49	5.85
18778.86e	4.08	6.15	0.49	5.32
18808.78e	3.62	5.64	2.37	5.48
18811.78e	6.62	5.48	5.37	5.72
18820.77f	0.42	4.68	0.33	5.32
18820.82f	0.47	5.00	0.38	5.16
18821.79f	1.44	5.48	1.35	5.85
18824.79f	4.44	5.92	4.35	6.02
18825.73f	5.38	6.03	5.29	5.91
18825.77f	5.42	6.26	5.33	6.07
18827.76f	7.41	4.84	0.31	5.24
18828.75f	0.81	5.16	1.30	5.32
18830.73e	2.79	5.32	3.28	5.72
18831.68f	3.74	5.92	4.23	5.91
18831.75f	3.81	6.03	4.30	6.12
18848.63f	5.50	6.38	0.15	5.00
18849.70f	6.57	5.32	1.22	5.48
18852.65q	1.92	5.48	4.17	5.64
18852.70e	1.97	5.16	4.22	5.85
18855.75f	5.02	6.26	0.26	5.32
18856.68f	5.95	6.03	1.19	5.48
18859.60e	1.28	5.16	4.11	5.72
18859.65f	1.33	5.16	4.16	5.64
18859.68q	1.36	5.32	4.19	5.64
18862.66f	4.34	5.92	0.16	5.16
18866.59f	0.67	4.68	4.09	5.91
18878.64f	5.13	5.92	2.12	5.85
18884.63f	3.52	6.15	1.09	5.32
18885.61f	4.50	6.38	2.07	5.91
18887.59f	6.48	5.32	4.05	6.12
18890.61q	1.91	5.64	0.06	4.60
18892.62f	3.92	6.15	2.07	5.91
18904.58q	0.69	5.00	0.01	4.60
18908.54f	4.65	6.15	3.97	5.96
18911.53f	0.04	4.68	6.96	5.08
18912.53f	1.04	4.68	0.95	5.40
18917.51f	6.02	5.64	5.93	5.91
18919.55f	0.47	5.00	0.96	5.32
18939.51f	5.24	5.92	6.90	5.32
19149.80f	2.87	6.03	6.85	4.84
19153.84f	6.91	5.48	3.88	5.96
19157.84f	3.31	5.92	0.87	4.84
19159.86f	5.33	6.38	2.89	5.64
19162.83q	0.71	5.24	5.86	5.32
19184.73e	7.42	4.68	6.73	5.16
19189.76q	4.85	5.92	4.74	5.72

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and	W Sgr		X Sgr		J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Telescope	Phase	Mag.	Phase	Mag.
19191.67e	6.76	5.32	6.65	5.00	19271.55e	3.10	5.92	2.40	5.48
19203.71f	3.61	6.03	4.67	5.72	19271.61q	3.16	5.80	2.46	5.64
19204.74f	4.64	6.26	5.70	6.02	19276.56f	0.51	5.16	0.40	5.16
19208.72q	1.03	5.08	2.67	5.48	19286.54q	2.90	5.64	3.37	5.64
19213.63f	5.94	5.80	0.57	5.00	19288.50f	4.86	5.92	5.33	5.85
19215.74f	0.45	5.16	2.68	5.96	19292.56f	1.32	5.32	2.38	5.32
19218.70q	3.41	5.80	5.64	5.72	19300.50f	1.67	5.32	3.31	6.07
19219.64e	4.35	5.80	6.58	5.32	19302.51f	3.68	5.64	5.32	6.02
19219.68q	4.39	5.92	6.62	4.84	19311.53f	5.10	6.03	0.31	5.32
19224.65f	1.77	5.48	4.58	6.07	19487.88e	6.77	5.48	1.38	5.00
19225.61f	2.73	5.48	5.56	6.02	19510.81f	6.91	4.84	3.28	5.48
19233.62f	3.14	5.48	6.54	5.32	19511.78f	0.29	4.60	4.25	5.80
19233.66f	3.18	6.15	6.58	5.48	19511.82f	0.33	5.00	4.29	5.91
19237.63f	7.15	5.16	3.54	5.91	19513.83e	2.34	5.16	6.30	5.16
19240.60f	2.53	5.48	6.51	5.85	19517.78f	6.29	6.03	3.24	5.80
19240.63q	2.56	5.48	6.54	5.48	19518.78f	7.29	4.52	4.24	5.91
19241.61f	3.54	6.15	0.51	5.48	19518.82f	7.33	4.92	4.28	5.91
19243.62q	5.55	6.15	2.52	5.48	19520.83e	1.74	5.32	6.29	5.32
19244.63q	6.56	5.80	3.53	5.64	19532.72f	6.04	5.80	4.16	5.91
19253.60f	0.34	5.00	5.48	6.12	19541.76e	7.48	5.16	6.19	5.00
19264.60f	3.74	6.26	2.46	5.91	19541.79f	7.51	4.76	6.22	5.16
19267.56f	6.70	5.32	5.42	5.96	19542.85f	0.98	5.00	0.27	4.68
19268.57q	0.12	4.52	6.43	5.24	19545.76f	3.89	5.92	3.18	5.80
19270.55q	2.10	5.48	1.40	5.32	19545.81f	3.94	5.80	....	....

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and	W Sgr		X Sgr		J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Telescope	Phase	Mag.	Phase	Mag.
19557.74e	0.68	5.00	1.13	5.16	19657.56f	1.76	5.00	....	....
19561.72f	4.66	6.15	5.11	5.91	19688.52f	2.34	5.16	5.71	5.91
19561.77f	4.71	6.15	5.16	5.80	19711.53f	2.57	5.32	0.68	4.84
19562.69f	5.63	6.15	6.08	5.16	19865.87e	5.01	6.03	0.77	4.84
19572.70f	0.45	5.16	2.07	5.32	19888.84q	5.20	6.15	2.71	5.48
19574.72q	....	....	4.09	5.72	19889.83f	6.19	5.64	3.70	5.96
19576.71q	4.46	6.26	6.08	5.72	19889.88f	6.24	6.15	3.75	5.91
19588.67e	1.23	5.00	4.02	5.72	19898.87f	0.04	5.00	5.73	5.80
19588.72f	1.28	5.32	4.07	6.12	19902.83q	4.00	5.92	2.68	5.64
19593.66f	6.22	5.92	2.00	5.48	19911.85f	5.42	6.15	4.69	5.80
19593.71f	6.27	6.15	2.05	5.16	19911.90f	5.47	6.03	4.74	5.72
19599.64f	4.60	5.92	0.97	5.48	19912.80f	6.37	6.03	5.64	5.56
19601.64f	6.60	5.32	2.97	5.64	19917.73e	3.71	5.80	3.55	5.64
19603.61f	0.98	4.76	4.94	6.02	19917.78q	3.76	6.03	3.60	5.64
19603.65f	1.02	5.16	4.98	5.91	19921.75e	0.13	4.68	0.56	5.16
19604.55f	1.92	5.16	5.88	5.32	19921.75q	0.13	4.72	0.56	5.00
19617.58f	7.35	4.52	4.88	6.07	19921.77f	0.15	4.52	0.58	5.32
19620.57f	2.75	5.32	0.86	5.48	19922.82f	1.20	5.16	1.63	5.00
19632.53f	7.12	4.84	5.81	5.48	19928.76q	7.14	5.24	0.56	4.84
19632.58f	7.17	5.00	5.86	5.32	19930.60f	1.39	5.16	2.40	5.32
19644.56f	3.95	5.92	3.82	5.80	19931.66f	2.45	5.32	3.46	5.32
19645.63f	5.02	6.03	4.89	5.91	19942.76f	5.95	6.03	0.54	4.68
19650.57f	2.37	5.16	2.82	5.91	19943.75f	6.94	5.16	1.53	5.48
19650.65f	2.45	5.32	2.90	5.80	19947.66e	3.22	5.48	5.44	5.48

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and	W Sgr		X Sgr		J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Telescope	Phase	Mag.	Phase	Mag.
19947.70q	3.30	5.80	5.48	5.64	20012.57f	7.41	5.08	0.24	5.00
19947.72f	3.32	5.48	5.50	5.48	20012.61f	7.45	4.52	0.28	5.00
19950.71f	6.31	6.03	1.48	4.84	20013.56f	0.80	5.00	1.23	4.68
19951.68f	7.28	5.00	2.45	5.32	20015.52	2.76	5.92	....	....
19951.72f	7.32	5.00	2.49	5.48	20024.53q	4.18	5.92	5.19	5.64
19952.75f	0.75	4.84	3.52	5.64	20027.56f	7.21	5.08	1.21	4.84
19955.71q	3.71	5.80	6.48	5.24	20029.51f	1.57	5.00	3.16	5.48
19957.60f	5.60	5.92	1.36	5.00	20038.52f	2.98	5.56	5.15	5.64
19958.68f	6.68	5.32	2.44	5.48	20043.57f	0.43	4.84	3.19	5.64
19959.58f	7.58	5.00	3.34	5.96	20044.52f	1.38	5.16	4.14	5.80
19961.60f	2.01	5.48	5.36	5.64	20044.56f	1.42	5.16	4.18	5.64
19970.67q	3.48	5.80	0.41	4.68	20047.52f	4.38	5.92	0.13	4.84
19972.66f	5.47	5.98	2.40	5.56	20228.87q	3.45	5.64	6.20	5.48
19973.51f	6.32	5.92	3.25	5.96	20240.87q	0.26	4.92	4.18	5.72
19973.56f	6.37	5.92	3.30	5.85	20246.86q	6.25	5.72	3.16	5.64
19974.60q	7.41	4.84	4.34	5.80	20255.84q	0.04	4.68	5.13	5.72
19976.61f	1.83	5.32	6.35	5.80	20259.84q	4.04	5.92	2.12	5.64
19976.62q	1.84	5.48	6.36	5.48	20276.76e	5.77	5.03	5.02	5.80
19977.67f	2.89	5.64	0.39	4.68	20277.78q	6.79	5.48	6.04	5.64
19982.59f	0.21	4.68	5.31	5.56	20280.76e	2.18	5.48	2.00	5.00
19985.52f	3.14	6.09	1.23	5.32	20280.76q	2.18	5.48	2.00	5.16
19989.52f	7.14	5.40	5.23	5.91	20282.76f	4.18	6.03	4.00	5.40
19999.58q	2.01	5.64	1.27	5.00	20283.77q	5.19	6.03	5.01	5.91
20008.51f	3.35	5.92	3.19	5.48	20286.73q	0.55	5.32	0.96	4.92

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

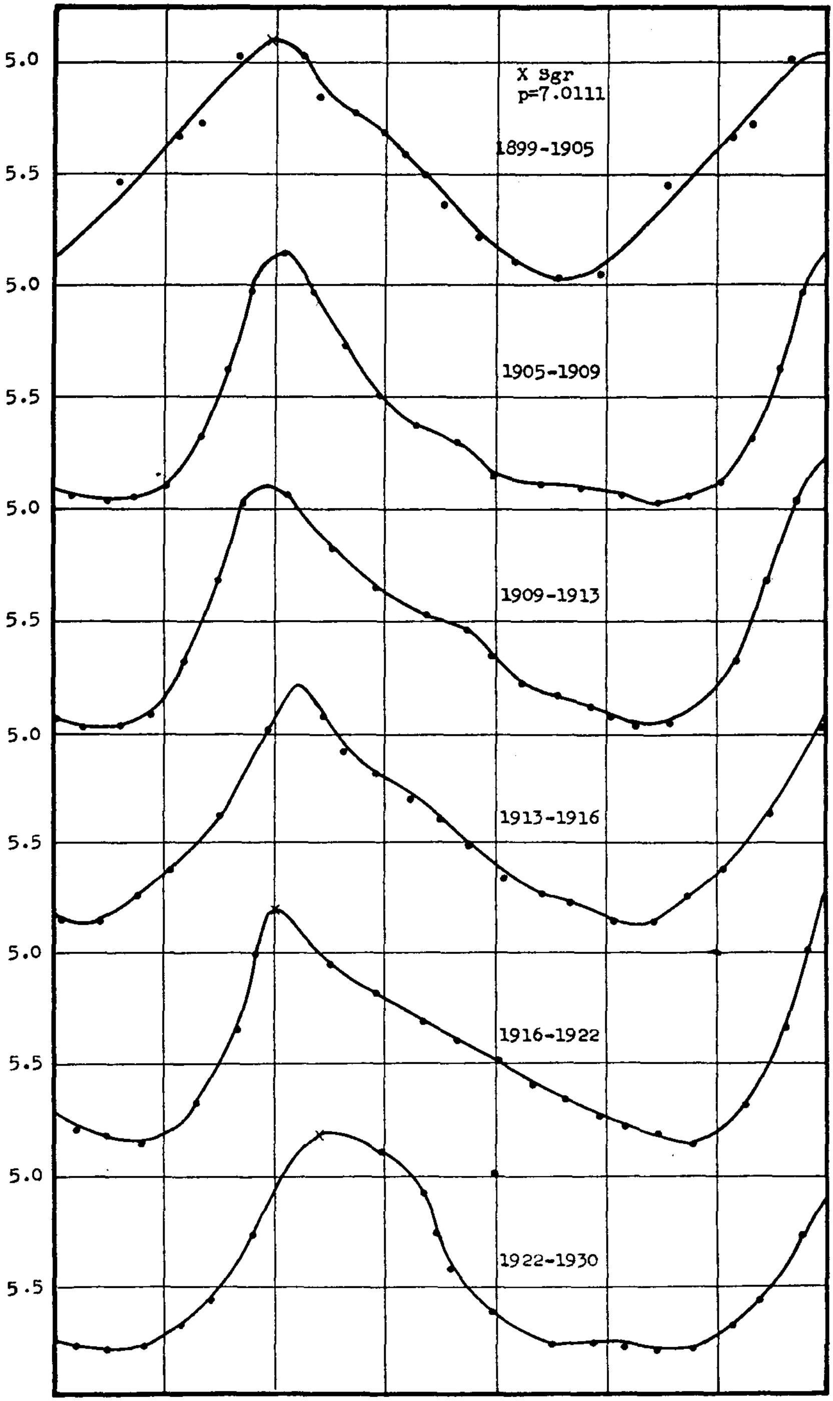
SECTION B

J. D. and Telescope	W Sgr		X Sgr	
	Phase	Mag.	Phase	Mag.
20286.78f	0.60	4.84	1.01	5.00
20287.64f	1.46	5.00	1.87	5.48
20289.69f	3.51	5.64	3.92	5.72
20294.76q	0.99	5.32	1.98	5.32
20296.73q	2.96	5.64	3.95	5.64
20297.67f	3.90	5.32	4.89	5.91
20297.70e	3.93	6.15	....	....
20298.72q	4.95	6.03	5.94	5.64
20300.73q	6.96	5.48	0.94	5.40
20301.67e	0.30	5.16	1.88	5.00
20301.72q	0.35	4.68	1.93	5.40
20304.71f	3.34	5.48	4.92	5.64
20306.75f	5.38	6.15	6.96	5.16
20307.56f	6.19	5.80	0.76	4.84
20307.74f	6.37	6.09	0.94	5.00
20308.70f	7.33	4.68	1.90	5.56
20309.65e	0.69	5.16	2.85	5.16
20309.70q	0.74	5.32	2.90	5.80
20313.69f	4.73	6.26	6.89	5.16
20314.70f	5.74	6.03	0.89	5.32
20315.69f	6.73	5.64	1.88	5.48
20317.68q	1.12	5.56	3.87	5.72
20324.66f	0.51	5.32	3.84	5.64
20327.65f	3.50	6.03	6.83	5.00
20327.70f	3.55	6.03	6.88	4.76
20328.60f	4.45	6.15	0.77	5.32
20329.64f	5.49	6.15	1.81	5.48
20329.69f	5.54	6.03	1.86	5.32
20330.67f	6.52	6.15	2.84	5.64
20332.63e	0.88	4.68	4.80	5.64
20336.63f	4.88	6.26	1.79	5.48
20337.66f	5.91	5.64	2.82	5.32
20338.67f	6.92	5.16	3.83	5.96
20339.68f	0.34	4.60	4.84	5.96
20348.59f	1.65	5.64	6.73	5.32
20348.62f	1.68	5.16	6.76	4.84
20352.65f	5.71	6.26	3.78	5.64
20354.58f	0.05	5.00	5.71	5.91
20356.66f	2.13	5.16	0.78	4.84
20365.60f	3.47	5.92	2.71	5.16
20366.58f	4.45	6.03	3.69	5.99
20367.54f	5.41	6.38	4.65	5.85
20367.59f	5.46	6.15	4.70	5.64
20370.61q	0.89	5.48	0.71	4.68
20372.62f	2.90	5.80	2.72	5.80
20373.62f	3.90	6.03	3.72	5.64
20384.53f	7.21	5.32	0.61	5.00
20384.53q	7.21	5.32	....	....

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and Telescope	W Sgr		X Sgr	
	Phase	Mag.	Phase	Mag.
20384.58f	7.26	4.84	0.66	5.32
20386.52q	1.61	5.64	2.60	5.48
20391.53f	6.62	5.32	0.60	4.68
20392.54q	0.03	4.68	1.61	5.16
20393.58f	1.07	5.32	2.65	5.64
20394.53f	2.02	5.32	3.60	5.91
20413.49q	5.79	5.92	1.52	5.16
20414.54f	6.84	5.64	2.57	5.32
20426.56f	3.69	6.03	0.57	5.16
20440.54f	2.46	5.16	0.53	5.00
20567.91q	0.72	5.16	1.70	5.16
20572.90q	5.71	6.15	6.69	5.00
20577.88q	3.09	5.92	4.66	5.80
20596.84q	6.86	5.64	2.58	5.16
20605.85q	0.68	5.48	4.58	5.80
20626.82f	6.46	5.48	4.52	5.85
20627.81q	7.45	4.68	5.51	5.64
20628.75q	0.80	5.16	6.45	5.56
20650.76e	0.02	4.84	0.41	4.68
20651.84f	1.10	5.16	1.49	5.32
20653.81f	3.07	5.92	3.46	5.85
20655.76f	5.02	6.15	5.41	5.85
20657.69e	6.95	5.48	0.33	5.16
20664.76f	6.43	5.48	0.39	4.68
20668.76f	2.83	5.92	4.39	5.80
20669.75f	3.82	5.64	5.38	5.64
20670.66f	4.73	6.03	....	....
20680.66f	7.14	5.48	2.27	5.32
20681.71f	0.59	5.00	3.32	5.96
20683.62f	2.50	5.16	5.23	5.99
20688.67f	0.55	4.68	3.27	5.64
20688.71f	0.00	4.92	3.31	5.96
20689.62f	0.91	5.32	4.22	5.72
20691.62f	2.91	5.80	6.22	5.48
20693.61f	4.90	6.03	1.20	5.32
20694.65f	5.94	6.03	2.24	5.80
20695.62f	6.91	5.16	3.21	5.48
20695.66f	6.96	5.32	3.25	5.80
20723.65f	4.56	6.03	3.19	5.32
20723.65f	4.56	6.15	3.19	5.64
20724.61f	5.52	6.38	4.15	5.85
20741.56f	7.28	4.68	0.07	4.52
20747.52f	5.64	6.15	6.03	5.48
20750.52f	1.05	5.16	2.02	5.16
20754.51f	5.04	6.15	6.01	5.32
20755.77f	6.30	5.92	0.26	4.68
20769.48f	4.82	6.15	6.95	5.32
20775.51f	3.25	6.15	5.97	5.48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1899-1905
1905-1909
1909-1913
1913-1916
1916-1922
1922-1930

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and	W Sgr		X Sgr		J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Telescope	Phase	Mag.	Phase	Mag.
20932.85f	1.10	5.16	2.06	5.32	21044.67e	6.59	5.16	1.70	5.32
20934.90q	3.15	6.03	4.11	5.72	21047.67f	1.99	5.32	4.70	5.80
20949.84q	2.90	5.80	5.02	5.64	21049.63f	3.95	5.92	6.66	5.32
20964.83e	2.70	5.32	5.99	5.91	21050.64f	4.96	6.15	0.66	5.32
20973.81q	4.08	5.80	0.95	5.24	21062.59f	1.72	5.32	5.60	6.02
20990.76f	5.84	6.03	3.88	5.91	21062.63f	1.76	5.32	5.64	5.85
20994.80f	2.29	5.24	0.91	5.48	21063.63f	2.76	5.97	6.64	5.16
20995.74f	3.23	5.92	1.85	5.48	21064.62q	3.75	6.03	0.62	4.68
21005.75q	5.64	5.92	4.85	5.72	21066.59f	5.72	6.03	2.59	5.64
21006.76f	6.65	5.16	5.86	5.48	21077.60f	1.54	5.64	6.58	5.00
21006.79f	6.68	5.48	5.89	5.48	21077.62q	1.56	5.64	6.60	5.32
21007.74f	0.04	5.16	6.84	5.00	21091.55e	0.30	4.84	6.51	5.64
21007.78f	0.08	5.00	6.88	5.00	21105.56q	6.72	5.64	6.50	5.64
21009.77f	2.07	5.32	1.85	5.32	21123.52q	1.89	5.48	3.43	5.48
21010.74q	3.04	5.72	2.82	5.48	21129.52q	0.30	4.68	2.41	5.48
21011.71f	4.01	5.92	3.79	5.85	21133.52q	4.30	6.03	6.41	5.32
21011.76f	4.06	6.15	3.84	5.91	21135.49f	6.27	5.92	1.37	4.84
21012.72f	5.02	6.15	4.80	5.85	21135.52f	6.30	5.80	1.40	5.00
21013.72f	6.02	5.92	5.80	5.96	21136.51f	7.29	4.60	2.39	5.48
21016.74q	1.44	5.48	1.81	5.16	21137.53f	0.71	5.16	3.41	5.48
21018.75f	3.45	5.64	3.82	5.64	21154.50f	2.50	5.32	6.36	4.84
21021.76f	6.46	5.64	6.83	5.16	21155.51f	3.51	5.48	0.36	5.00
21025.73f	2.84	5.32	3.79	5.64	21160.49f	0.89	5.32	....	....
21036.76q	6.27	5.92	0.80	5.32	21313.90q	2.40	5.64	4.50	5.72

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and	W Sgr		X Sgr		J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Telescope	Phase	Mag.	Phase	Mag.
21318.84q	7.34	4.68	2.43	5.24	21437.56f	4.54	6.03	1.96	5.32
21334.86q	0.58	5.32	4.43	5.64	21445.61q	5.00	6.26	3.00	5.48
21344.84f	2.96	5.48	0.39	4.84	21447.58f	6.97	5.32	4.97	5.96
21364.83f	0.17	5.16	6.36	5.16	21449.58f	1.37	5.32	6.97	4.84
21365.73f	1.07	5.00	0.25	4.52	21452.57f	4.36	6.15	2.95	5.32
21366.80q	2.14	5.56	1.32	5.00	21454.57f	6.36	5.48	4.95	5.64
21368.73f	4.07	6.03	3.25	5.56	21456.54f	0.74	5.00	6.92	4.84
21370.75f	6.09	6.26	5.27	6.04	21516.52f	7.55	5.00	3.80	5.64
21372.70f	0.44	4.52	0.20	4.68	21523.51f	6.95	5.32	3.78	5.64
21372.74f	0.48	4.52	0.24	5.00	21654.92q	0.38	5.16	1.98	5.32
21391.75f	4.30	5.92	5.23	5.80	21670.88q	1.15	5.64	3.92	5.64
21394.72f	7.27	5.00	1.19	5.00	21730.74q	0.25	5.32	0.68	5.00
21397.70e	2.66	5.48	4.17	5.80	21731.76f	2.54	5.48	1.70	5.48
21397.70f	2.66	5.32	4.17	5.64	21732.75f	3.53	6.03	2.69	5.16
21407.68e	5.04	6.09	0.13	5.00	21748.63e	4.22	5.92	4.54	5.64
21421.62f	3.79	5.92	0.05	4.68	21748.77q	4.36	6.03	4.68	5.64
21424.58f	6.75	5.32	3.01	5.85	21749.75f	5.34	6.15	5.66	5.80
21424.63f	6.80	5.64	3.06	5.85	21751.65f	7.24	4.68	0.55	5.16
21425.58f	0.16	4.84	4.01	5.91	21757.74q	5.73	6.03	6.64	5.32
21426.59f	1.17	5.16	5.02	5.91	21776.65f	1.86	5.32	4.52	5.96
21427.58f	2.16	5.32	6.01	5.64	21786.60f	4.21	5.92	0.45	5.16
21427.62f	2.20	5.32	6.05	5.80	21787.61f	5.22	6.15	1.46	4.84
21430.60f	5.18	6.03	2.02	5.48	21788.63f	6.24	6.03	2.48	5.16
21431.58f	6.16	5.48	3.00	5.48	21789.59f	7.20	5.00	3.44	5.64

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and	W Sgr		X Sgr		J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Telescope	Phase	Mag.	Phase	Mag.
21801.61q	4.03	5.64	....	....	22083.86f	5.27	6.38	3.24	5.96
21804.58f	7.00	5.48	4.40	5.91	22104.78q	3.40	5.80	3.12	5.48
21804.62q	7.04	5.48	4.44	5.64	22133.64f	1.88	5.32	3.94	5.48
21806.57f	1.40	5.48	6.39	5.48	22138.67e	6.91	5.48	1.96	5.48
21806.66f	1.49	5.16	6.48	5.16	22161.55f	7.01	5.00	3.81	5.85
21807.62q	....	....	0.43	5.32	22161.59f	7.05	4.84	3.85	5.99
21810.58f	5.41	6.26	3.39	5.64	22164.55f	2.41	5.64	6.81	5.32
21812.59f	7.42	5.00	5.40	5.64	22165.54f	3.40	5.92	0.78	5.32
21818.51f	5.74	6.38	....	....	22166.51f	4.37	6.09	1.75	5.32
21818.58f	5.81	6.15	4.38	5.91	22169.61q	7.47	4.76	....	....
21819.55f	6.78	5.32	5.35	5.64	22191.59f	6.67	5.56	5.80	6.07
21825.56q	5.20	6.03	4.35	6.02	22192.57f	0.05	4.52	6.78	5.56
21833.59q	5.63	5.72	5.37	5.91	22197.56e	5.04	5.92	4.76	5.72
21834.54f	6.58	5.48	6.32	5.56	22225.53f	2.63	5.92	4.68	6.07
21834.60q	6.64	5.48	6.38	5.64	22514.66f	3.15	6.03	6.36	5.32
21839.55q	4.00	5.92	4.32	5.72	22516.60f	5.09	6.03	1.29	5.32
21847.57q	4.42	5.80	5.33	5.91	22520.63f	1.53	5.64	5.32	5.64
21859.52q	1.18	5.16	3.25	5.48	22522.66q	3.56	5.80	0.34	4.84
21866.51f	0.58	4.76	3.23	5.48	22523.60f	4.50	5.80	1.28	5.16
21867.51f	1.58	5.48	4.23	5.91	22573.51f	1.25	5.48	2.11	5.64
22070.78e	7.38	4.52	4.18	5.48	22580.51f	0.65	5.32	2.10	5.32
22071.79e	0.79	4.84	5.19	5.96	22580.56f	0.70	5.24	2.15	5.48
22072.83q	1.83	5.64	6.23	5.64	22843.73e	5.64	5.92	5.90	5.64
22076.80q	5.80	6.15	3.19	5.32	22843.73q	5.64	6.15	5.90	5.96

TABLE IV.—Photographic Observations of Cepheid Variable Stars.—*Cont.*

Section B

J. D. and	W Sgr		X Sgr		J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Telescope	Phase	Mag.	Phase	Mag.
22846.74q	1.06	5.64	1.90	5.16	23199.78f	4.73	5.97	4.38	5.80
22855.73q	2.45	5.64	3.88	5.48	23202.80q	0.15	4.84	0.39	5.16
22905.61q	6.76	5.92	4.68	5.64	23204.83q	2.18	5.16	2.42	5.64
22910.59e	4.15	5.92	2.65	5.64	23205.65f	3.00	5.48	3.24	5.91
22935.53f	6.30	5.48	6.56	5.64	23206.69f	4.04	6.15	4.28	6.07
23168.87q	4.20	5.72	1.52	5.24	23209.72f	7.07	5.16	....	....
23169.77f	5.10	6.03	2.42	5.16	23222.72f	4.88	6.38	....	....
23169.82q	5.15	6.15	2.47	5.48	23225.70f	0.27	5.00	2.26	5.32
23172.83f	0.56	5.00	5.48	5.91	23228.66q	3.23	6.03	....	....
23172.88f	0.61	5.00	5.53	5.96	23229.79q	4.36	5.80	6.35	5.96
23175.83q	3.56	5.72	1.47	5.00	23232.64q	7.21	4.68	2.19	5.00
23175.84e	3.57	5.64	1.48	5.48	23233.66f	0.63	4.76	3.21	5.64
23176.83f	4.56	5.80	2.47	5.32	23235.68f	2.65	5.48	5.23	5.96
23177.83f	5.56	5.92	3.47	5.64	23237.63f	4.60	6.03	0.17	5.32
23178.81f	6.54	5.32	4.45	5.96	23239.67f	6.64	5.48	2.21	5.32
23179.70f	7.43	4.84	5.34	5.96	23248.59f	0.37	5.16	4.12	5.96
23180.81q	0.95	5.16	6.45	5.00	23250.70q	2.48	5.32	6.23	5.32
23180.82f	0.96	5.48	....	....	23251.64q	3.42	5.92	0.16	5.00
23181.77f	1.91	5.48	0.40	5.32	23253.61f	5.39	6.26	2.13	5.48
23181.82f	1.96	5.32	0.45	5.32	23257.60q	1.79	5.32	6.12	5.48
23193.77f	6.31	5.92	5.39	5.91	23258.59q	2.78	5.32	0.09	5.32
23194.75f	7.29	5.32	....	....	23262.61f	6.80	5.48	4.11	5.80
23194.81q	7.35	4.84	6.43	5.48	23265.58f	2.17	5.32	0.07	5.48
23198.77f	3.72	5.80	3.37	5.64	23267.55f	4.14	5.92	2.04	5.48

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.
23267.59f	4.18	6.03	2.08	5.32
23267.60q	4.19	5.80	2.09	5.16
23268.57f	5.16	6.15	3.06	5.48
23268.61f	5.20	6.15	3.10	5.48
23272.54f	1.54	5.32	....	....
23275.51f	4.51	6.15	2.99	5.91
23276.51f	5.51	6.15	3.99	5.96
23276.55f	5.55	6.03	....	....
23277.52f	6.52	5.92	5.00	6.07
23280.53f	1.93	5.48	1.00	5.16
23305.56q	4.18	5.80	5.00	5.85
23306.51f	5.13	6.38	....	....
23306.53q	5.15	5.92	5.97	5.96
23307.54q	6.16	5.80	6.98	5.64
23309.52q	0.54	5.00	1.95	4.92
23311.52f	2.54	5.80	3.95	5.64
23311.52q	2.54	5.48	3.95	5.64
23313.51q	4.53	5.80	5.94	5.64
23314.51q	5.53	5.92	6.94	5.48
23319.52q	2.95	5.48	4.93	5.64
23324.56q	0.39	4.52	2.96	5.96
23346.52f	7.16	5.32	3.89	6.07
23518.87e	4.83	6.15	0.96	5.16
23533.74f	4.51	5.98	1.81	5.48
23535.69f	6.46	5.48	3.76	5.64
23535.78f	6.55	5.92	3.85	5.48
23546.79e	2.37	5.32	0.84	5.64
23561.73f	2.12	5.32	1.75	5.32
23575.77f	0.97	5.16	1.77	4.68
23576.78f	1.98	5.16	2.78	5.80
23587.65q	5.25	6.15	6.64	4.56
23589.73q	7.33	4.68	1.71	4.84
23601.59e	4.00	6.15	6.56	4.68
23605.68q	0.50	4.84	3.64	5.64
23609.73q	4.55	5.80	0.68	4.84
23610.62f	5.44	6.15	1.57	5.08
23616.64f	3.86	5.80	0.58	5.32
23641.60f	6.04	5.92	4.50	5.80
23641.63q	6.07	5.48	4.53	5.64
23642.59q	7.03	5.48	5.49	5.64
23645.60q	2.44	5.32	1.49	5.00
23664.56f	6.21	6.15	6.43	5.91
23903.83q	2.44	5.48	0.31	5.32
23947.72q	0.76	5.16	2.13	5.32
23974.69q	4.95	6.03	1.06	4.84
23985.59e	0.66	5.00	4.95	5.80
24000.64q	0.52	4.52	5.97	5.96
24233.90e	5.93	5.64	0.85	5.16

TABLE IV.—Photographic Observations of Cepheid Variable Stars.—*Cont.*

Section B

J. D. and	W Sgr		X Sgr		J. D. and	W Sgr		X Sgr	
Telescope	Phase	Mag.	Phase	Mag.	Telescope	Phase	Mag.	Phase	Mag.
24241.84e	6.28	5.48	1.78	5.48	24659.75q	6.46	6.03	6.03	5.48
24246.88q	3.72	5.80	6.82	5.48	24670.80q	2.32	5.00	....	....
24247.84e	4.68	6.38	0.77	4.68	24676.73q	0.66	5.32	1.98	5.32
24256.81e	6.06	5.80	2.73	5.32	24678.74q	2.67	5.64	3.99	5.64
24274.78e	1.24	5.48	6.68	5.16	24679.68q	3.61	5.92	....	....
24275.80e	2.26	5.48	0.69	5.64	24683.66q	0.00	4.68	1.90	5.00
24298.74q	2.42	5.80	2.59	5.64	24683.77q	0.11	4.68	2.01	5.16
24314.69e	3.18	5.64	4.52	5.64	24688.68e	5.02	5.92	6.92	5.48
24314.74q	3.23	5.80	4.57	5.64	24695.59e	4.33	6.26	....	....
24315.71e	4.20	5.80	5.54	5.64	24697.68e	6.42	5.16	....	....
24322.69q	3.58	6.15	5.51	5.64	24697.70q	6.44	5.64	1.92	4.84
24328.68q	1.98	5.48	4.49	5.64	24700.66q	1.80	5.64	4.88	5.96
24332.67q	5.97	6.26	1.47	5.16	24709.73q	3.28	5.64	6.94	5.64
24332.68e	5.98	5.64	1.48	5.16	24716.64q	2.59	5.48	....	....
24334.74q	0.44	4.68	3.54	5.91	24766.58q	6.96	4.68	0.69	4.52
24343.69q	1.80	5.64	5.48	5.72	24770.53q	3.32	5.48	4.64	5.64
24352.66q	3.17	5.64	0.42	5.32	24770.58q	3.37	5.80	4.69	5.80
24626.79q	3.88	6.15	1.12	4.68	24780.52q	5.71	6.03	0.60	5.32
24640.80e	2.70	5.48	1.11	5.48	24943.89q	1.99	5.32	2.72	5.24
24640.83q	2.73	5.48	1.14	5.00	24999.78q	4.72	6.15	2.52	5.16
24644.74q	6.64	5.92	5.05	5.80	25033.74q	0.70	5.32	1.42	5.32
24648.81q	3.12	5.64	2.11	5.00	25037.73q	4.69	5.92	5.41	5.72
24656.72e	3.43	5.64	3.00	5.91	25062.69q	6.87	5.32	2.33	5.00
24656.74q	3.45	5.92	....	....	25065.67q	2.25	5.80	5.31	5.48

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and Telescope	W Sgr		X Sgr	
	Phase	Mag.	Phase	Mag.
25086.62q	0.42	4.68	5.22	5.80
25087.62q	1.42	5.64	6.22	5.32
25096.65q	2.75	5.64	1.23	4.68
25097.63q	3.83	5.80	2.21	5.00
25108.64q	7.25	4.68	6.21	5.64
25118.60q	2.02	5.16	2.15	5.48
25132.53q	0.76	5.40	2.06	5.16
25333.95q	4.71	5.92	0.15	5.00
25354.84q	2.81	5.72	....	....
25379.78q	4.97	5.92	3.92	5.64
25409.74q	4.55	6.03	5.83	5.48
25413.66q	0.88	4.84	2.74	5.32
25436.65q	1.08	5.32	4.70	5.64
25444.64q	1.48	5.64	5.68	5.64
25452.58q	1.82	5.48	6.60	5.80
25521.53q	2.42	5.48	5.44	5.64
25712.83q	3.84	5.92	0.43	5.00
25739.77e	0.40	5.32	6.34	5.32
25739.80q	0.43	4.68	6.37	5.64
25741.81q	2.44	5.32	1.37	4.68
25742.81q	3.44	5.64	2.37	5.00
25765.68e	3.53	6.03	4.20	5.91
25767.79q	5.64	5.92	6.31	5.64
25773.78q	4.03	5.80	5.29	5.80
25779.71q	2.37	5.64	4.21	5.64
25790.64e	5.70	5.92	1.12	5.16
25793.70q	1.17	5.48	4.18	5.64
25797.70q	5.17	5.92	1.17	4.68
25800.66q	0.53	4.68	4.13	5.64
25801.63q	1.50	5.32	5.10	5.64
25807.68q	7.55	4.68	4.14	5.64
25808.68q	0.96	5.32	5.14	5.72
25826.60e	3.69	5.80	2.02	5.64
25826.62q	3.71	5.64	2.04	5.24
25830.63q	0.12	4.36	6.05	5.64
25850.55q	4.85	6.15	4.94	5.64
25876.52q	0.44	4.84	2.86	5.16

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

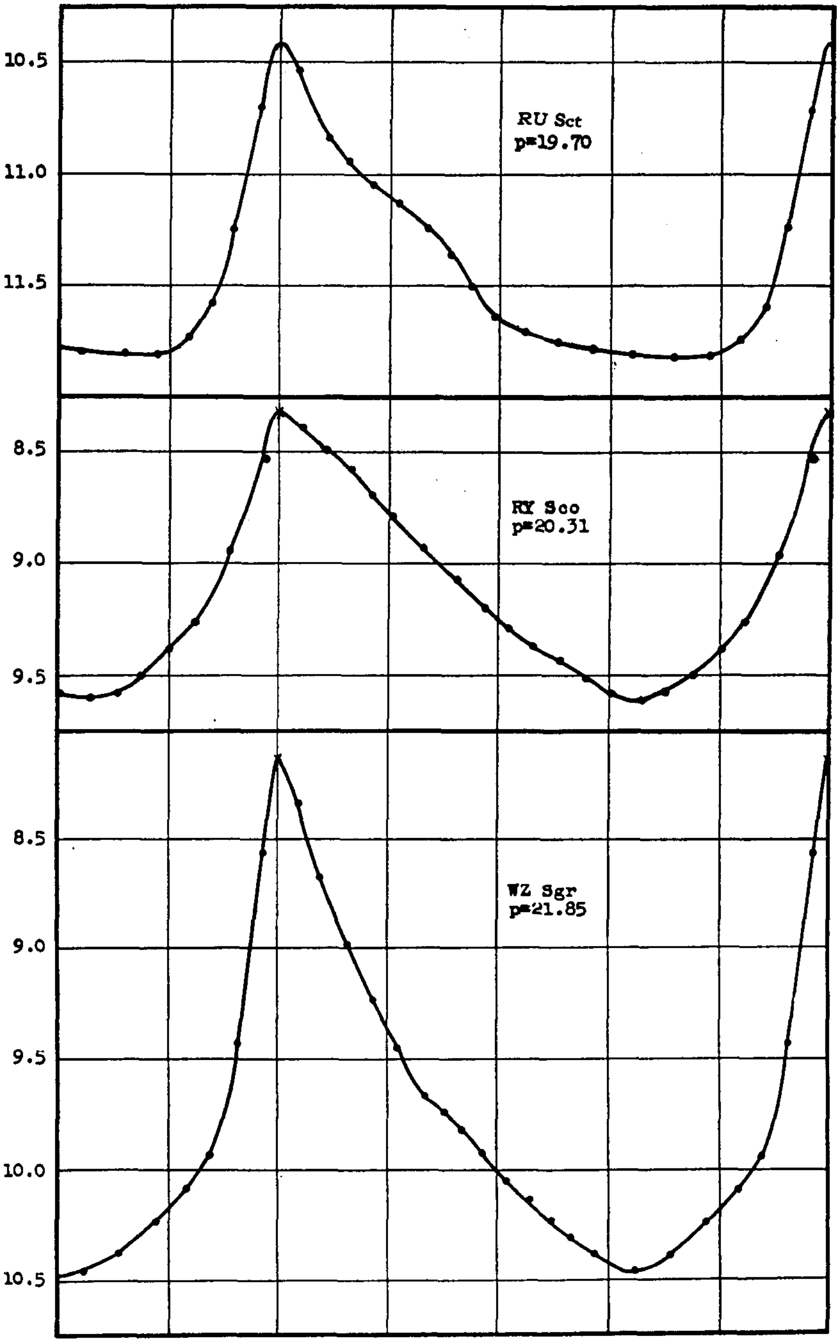
SECTION B

J. D. and Telescope	RV Sco		RY Sco		J. D. and Telescope	RV Sco		RY Sco	
	Phase	Mag.	Phase	Mag.		Phase	Mag.	Phase	Mag.
14862.62f	0.40	7.23	12.48	9.53	16683.52f	2.87	8.03	5.10	8.73
14904.57f	5.98	7.23	13.80	9.71	16697.67f	4.89	8.03	19.25	8.83
15148.72f	1.61	7.61	.....	....	16943.84f	2.55	7.96	1.34	8.53
15532.70f	3.72	8.16	12.19	9.53	16968.80f	3.26	7.96	5.99	9.04
15634.57f	2.54	7.80	12.49	9.71	16979.77f	2.11	7.71	16.96	9.34
15872.81f	4.39	8.22	6.96	9.09	17004.65f	2.74	8.03	1.21	8.34
15885.83f	5.29	7.61	19.98	8.53	17009.77f	1.80	7.61	6.33	8.93
15897.70f	5.03	7.96	11.53	9.62	17032.77f	0.55	7.23	9.01	9.24
15933.68f	....	....	6.89	9.04	17076.67f	2.02	7.71	12.29	9.62
15934.65f	5.61	7.32	7.86	9.14	17105.61f	0.66	7.23	0.60	8.43
15940.64f	5.54	7.52	13.85	9.62	17335.80f	0.51	7.42	7.33	9.14
16023.57f	3.61	8.09	15.52	9.62	17360.72f	1.19	7.52	11.94	9.53
16241.73f	3.56	8.16	10.22	9.34	17384.72f	0.94	7.42	15.62	9.62
16253.71f	3.42	8.09	1.89	8.53	17403.72f	1.76	7.61	14.31	9.44
16297.69f	4.97	7.96	5.24	8.93	17447.57f	3.18	8.03	17.53	9.29
16308.64f	3.80	8.16	16.19	9.53	17465.57f	2.99	8.09	15.22	9.62
16311.63f	0.72	7.32	19.18	8.93	17495.54f	2.66	7.96	4.56	8.78
16319.54f	2.57	7.96	6.78	9.14	17703.90f	4.93	7.80	9.78	9.24
16376.62f	5.10	7.71	2.92	8.53	17758.72f	5.19	7.71	3.65	8.53
16593.79f	4.06	8.09	16.94	9.34	17774.72f	3.01	8.03	19.65	8.53
16608.89f	0.97	7.52	11.73	9.44	17787.64f	3.81	8.22	12.26	9.62
16636.77f	4.61	8.09	19.30	8.83	17813.55f	5.47	7.32	17.86	9.34
16650.72f	0.37	7.23	12.93	9.53	17820.55f	0.35	7.04	4.54	8.83
16663.80f	1.33	7.61	5.70	8.88	18027.89f	1.60	7.61	8.74	9.34

TABLE IV.—Photographic Observations of Cepheid Variable Stars.—*Cont.*

Section B

J. D. and Telescope	RV Sco		RY Sco		J. D. and Telescope	RV Sco		RY Sco	
	Phase	Mag.	Phase	Mag.		Phase	Mag.	Phase	Mag.
18042.86f	4.45	8.16	3.40	8.63	19233.66f	1.15	7.32	15.98	9.44
18069.86f	1.14	7.61	10.08	9.53	19241.61f	3.03	8.03	....	....
18111.78f	0.63	7.32	11.37	9.44	19264.60f	1.78	7.80	6.29	9.14
18148.66f	1.14	7.52	7.63	9.04	19300.50f	1.31	7.52	1.56	8.53
18156.61f	3.03	8.09	15.58	9.34	19311.53f	....	....	12.59	9.53
18199.56f	3.55	8.09	17.90	9.24	19542.85f	1.20	7.52	0.14	8.53
18209.53f	1.40	7.61	7.55	9.24	19545.81f	4.16	8.09	3.10	8.58
18438.84f	....	....	....	....	19561.72f	1.89	7.80	19.01	8.68
18453.80f	3.21	7.96	8.05	9.24	19562.69f	2.86	8.03	19.98	8.53
18472.69f	3.92	8.16	6.63	9.09	19572.70f	0.75	7.23	9.68	9.44
18499.71f	0.63	7.13	13.35	9.62	19593.71f	3.57	8.09	10.37	9.44
18500.72f	1.64	7.52	14.36	9.53	19601.64f	5.44	7.52	18.30	9.14
18501.59f	2.51	7.90	15.23	9.39	19603.65f	1.39	7.61	0.00	8.35
18506.68f	1.54	7.52	0.00	8.15	19604.55f	2.29	7.80	0.90	8.53
18531.61f	2.22	7.71	4.61	8.93	19632.58f	0.01	7.04	8.61	9.44
18565.53f	5.83	7.13	18.21	9.14	19645.63f	0.94	7.52	....	....
18820.82f	0.48	7.23	9.42	9.34	19650.65f	5.96	7.04	6.37	9.04
18821.79f	1.45	7.61	10.39	9.39	19657.56f	0.75	7.23	13.28	9.71
18848.63f	4.05	8.28	16.92	9.44	19889.88f	2.73	7.90	1.83	8.53
18855.75f	5.11	7.71	3.72	8.78	19898.87f	5.66	7.13	10.82	9.39
18859.70f	2.99	8.16	7.67	9.24	19912.80f	1.41	7.52	4.44	8.83
18884.63f	3.68	8.09	12.29	9.62	19922.82f	5.36	7.52	14.46	9.53
18919.54f	2.22	7.80	6.57	9.14	19931.66f	2.08	7.71	2.98	8.73
19204.74f	2.53	7.80	7.37	9.14	19942.76f	1.06	7.61	14.08	9.53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11.0
11.5
RU Sct
p=19.70
8.5
9.0
9.5
RY Sco
p=20.31
8.5
9.0
9.5
10.0
10.5
WZ Sgr
p=21.85

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and Telescope	RV Sco		RY Sco	
	Phase	Mag.	Phase	Mag.
19947.72f	6.02	7.23	19.04	8.73
19950.71f	2.95	7.96	1.72	8.53
19951.72f	3.96	8.09	2.73	8.58
19959.58f	5.76	7.23	10.59	9.34
19961.60f	1.71	7.71	12.61	9.71
19973.51f	1.50	7.61	4.20	8.73
19977.67f	5.66	7.32	8.36	9.24
19985.52f	1.39	7.52	16.21	9.34
19989.52f	5.39	7.52	20.21	8.43
20012.57f	4.19	8.22	2.64	8.53
20013.56f	5.18	7.71	3.63	8.73
20044.57f	5.89	7.04	14.32	9.53
20297.67f	4.41	8.09	3.34	8.58
20306.74f	1.35	7.52	12.41	9.57
20307.56f	2.17	7.90	13.23	9.62
20328.60f	5.03	7.76	13.95	9.48
20329.69f	0.06	7.04	15.04	9.53
20330.67f	1.04	7.52	16.02	9.44
20337.66f	1.97	7.71	2.70	8.58
20338.58f	2.89	8.03	3.62	8.63
20354.58f	0.70	7.32	19.62	8.73
20366.58f	0.58	7.13	11.31	9.53
20367.59f	1.59	7.71	12.32	9.53
20372.62f	0.56	7.23	17.35	9.44
20384.53f	0.34	7.04	8.94	9.34
20414.54f	0.05	6.94	18.64	9.19
20681.71f	0.51	7.23	1.41	8.43
20688.71f	1.45	7.61	8.41	9.44
20691.62f	4.36	8.22	11.32	9.53
20695.66f	2.34	7.80	15.36	9.44
20747.52f	5.71	7.13	6.28	9.04
20769.48f	3.42	8.22	7.92	9.24
21006.79f	4.34	8.16	1.46	8.29
21007.78f	5.33	7.71	2.45	8.48
21009.83f	1.32	7.61	4.50	8.93
21011.76f	3.25	8.03	6.43	9.04
21048.68f	3.80	8.03	2.72	8.43
21062.63f	5.63	7.32	16.67	9.44
21063.63f	0.56	7.04	17.67	9.39
21066.63f	3.56	8.09	0.36	8.15
21135.52f	5.78	7.04	8.31	9.44
21137.53f	1.73	7.61	10.32	9.44
21364.83f	4.75	8.03	14.16	9.71
21424.63f	3.94	8.16	13.02	9.62
21427.62f	0.87	7.23	16.01	9.53
21788.63f	4.25	8.09	11.37	9.58
21806.66f	4.10	8.09	9.08	9.34
22166.51f	0.26	7.23	3.28	8.53

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and Telescope	RV Sco		RY Sco		J. D. and Telescope	RV Sco		RY Sco	
	Phase	Mag.	Phase	Mag.		Phase	Mag.	Phase	Mag.
22225.53f	4.73	8.09	1.36	8.53	23277.57f	....	....	17.37	9.24
22516.60f	4.85	8.16	8.03	9.14	23288.58f	0.97	7.52	....	....
22854.72f	3.53	8.09	0.81	8.35	23306.51f	0.72	7.13	5.69	8.83
22905.59f	5.91	7.32	11.05	9.53	23311.52f	....	....	10.70	9.34
23172.88f	0.44	6.94	14.26	9.53	23346.52f	4.36	8.09	5.07	8.73
23176.82f	4.38	8.03	18.20	9.14	23533.83f	3.76	8.03	9.55	9.29
23179.70f	1.20	7.52	0.76	8.29	23535.78f	5.71	7.23	11.50	9.44
23181.82f	3.32	8.16	2.88	8.43	23561.73f	....	....	17.14	9.34
23193.78f	....	....	14.84	9.71	23575.77f	3.27	8.03	10.86	9.62
23194.75f	4.12	8.09	15.81	9.44	23576.78f	4.28	8.16	....	....
23199.78f	3.09	7.96	0.53	8.53	23610.62f	....	....	5.08	8.73
23205.65f	2.80	8.03	6.40	8.88	23662.53f	5.17	7.61	16.37	9.24
23209.72f	0.91	7.32	10.47	9.34	23664.56f	1.14	7.61	18.40	9.04
23219.63f	4.76	8.03	0.06	8.29	23900.87z	1.06	7.23	10.94	9.39
23221.65f	0.72	7.42	2.08	8.35	23905.83z	6.02	7.13	15.90	9.34
23222.72f	1.79	7.52	3.15	8.68	23909.86z	3.98	8.03	19.93	8.48
23233.67f	0.61	7.23	14.10	9.53	23919.79z	1.79	7.71	9.54	9.53
23235.68f	2.62	7.96	16.11	9.44	23959.58z	5.21	7.61	8.70	9.24
23237.63f	4.57	8.03	18.06	9.04	23964.70z	4.27	8.09	13.82	9.53
23248.59f	3.41	7.96	8.71	9.34	23965.71z	5.28	7.52	14.83	9.53
23253.61f	2.37	7.80	13.73	9.53	23969.70z	....	....	18.82	9.04
23267.54f	4.18	8.16	7.34	9.14	23974.61z	2.06	7.61	3.42	8.63
23268.58f	5.22	7.71	8.38	9.14	23988.63z	3.96	8.03	17.44	9.04
23268.62f	5.26	7.61	8.42	9.14	23993.64z	2.90	7.96	2.14	8.53

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION B

J. D. and Telescope	RV Sco		RY Sco	
	Phase	Mag.	Phase	Mag.
24019.53z	4.55	8.03	7.71	9.24
24020.57z	5.59	7.52	8.75	9.34
24023.58z	2.54	7.80	11.76	9.34
24033.57z	0.40	7.23	1.44	8.29
24035.54z	2.37	7.96	3.41	8.73
24285.79z	4.11	8.16	9.89	9.34
24290.74z	2.99	8.03	....	....
24299.66z	5.85	7.32	3.44	8.73
24300.80z	0.93	7.52	4.58	8.83
24325.74z	1.63	7.61	9.21	9.24
24374.57z	1.96	7.52	17.41	9.14
24404.52z	1.61	7.61	6.73	8.93
24432.53z	5.37	7.61	14.43	9.73
24623.85z	2.73	7.96	2.61	8.43
24648.77z	3.40	8.03	....	....
24706.71z	....	....	4.21	8.73
24727.64z	....	....	4.83	8.93
24731.64z	1.41	7.61	8.83	9.24
24739.58z	....	....	16.77	9.14
24754.51z	0.04	7.13	11.38	9.34
24759.52z	5.05	7.96	16.39	9.14
24787.56z	2.78	8.03	3.80	8.68
24794.53z	3.69	8.09	....	....
25154.25z	5.78	7.23	4.84	8.83
25355.60z	1.04	7.42	3.05	8.73
25386.48z	1.62	7.61	....	....
25389.60z	4.74	7.96	16.73	9.24

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	S Nor Phase	S Nor Mag.	J. D. and Telescope	S Nor Phase	S Nor Mag.	J. D. and Telescope	S Nor Phase	S Nor Mag.
15274.58f	0.77	7.27	17039.56f	0.46	7.35	18187.57f	7.37	7.44
15519.62f	1.98	7.48	17069.62f	1.26	7.27	18361.89f	6.39	7.82
15590.66f	4.75	7.82	17094.59f	6.73	7.73	18467.76f	4.73	7.82
15646.54f	2.11	7.64	17297.84f	5.16	7.90	18507.70f	5.66	7.82
15872.89f	4.15	7.77	17352.83f	1.64	7.31	18533.51f	2.21	7.60
16183.87f	3.03	7.82	17376.80f	6.10	7.67	18856.73f	3.58	7.82
16254.78f	5.67	7.88	17401.72f	1.76	7.27	18897.60f	5.44	7.82
16288.60f	0.48	7.10	17464.56f	6.08	7.69	18917.60f	5.93	7.86
16310.73f	3.10	7.73	17499.52f	2.03	7.64	19177.81f	2.81	7.73
16311.59f	3.96	7.86	17738.79f	7.23	7.69	19180.80f	5.80	7.86
16359.56f	3.17	7.73	17758.76f	7.70	7.40	19239.59f	6.08	7.90
16558.87f	7.42	7.48	17772.74f	2.17	7.44	19312.52f	0.98	7.35
16563.76f	2.56	7.54	17803.61f	3.78	7.82	19575.69f	0.82	7.40
16593.75f	3.29	7.86	17835.54f	6.45	7.82	19595.71f	1.34	7.23
16604.74f	4.52	7.90	17843.53f	4.69	7.86	19599.69f	5.32	7.77
16607.80f	7.58	7.69	18026.88f	2.73	7.82	19648.57f	5.43	7.73
16650.67f	1.69	7.35	18041.86f	7.96	7.40	19903.73f	7.01	7.56
16653.61f	4.63	7.75	18070.79f	7.63	7.48	19917.79f	1.57	7.31
16697.57f	9.58	7.13	18082.86f	0.19	7.13	19925.78f	9.56	7.31
16706.60f	8.85	7.31	18102.56f	0.39	7.31	19942.85f	7.12	7.48
16915.89f	3.58	7.82	18109.69f	7.52	7.56	19971.68f	6.69	7.69
16968.75f	7.67	7.40	18145.57f	4.39	8.03	19974.63f	9.64	7.31
17000.78f	0.69	7.10	18150.66f	9.48	7.27	19978.65f	3.91	7.73
17032.82f	3.47	7.77	18159.52f	8.58	7.44	19985.61f	1.12	7.23

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and	S Nor		J. D. and	S Nor		J. D. and	S Nor	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
20012.53f	8.53	7.31	20654.74f	7.05	7.56	21037.63f	9.57	7.10
20279.70f	2.62	7.73	20662.73f	5.28	7.86	21038.59f	0.78	7.35
20282.80f	5.72	7.77	20667.66f	0.46	7.13	21047.72f	0.15	7.13
20287.73f	0.90	7.35	20667.71f	0.51	7.40	21051.66f	4.09	7.82
20294.67f	7.84	7.40	20669.69f	2.49	7.69	21078.54f	1.72	7.44
20295.81f	8.98	7.27	20681.74f	4.79	7.90	21080.55f	3.73	7.77
20313.74f	7.40	7.64	20690.69f	3.99	7.77	21081.54f	4.72	7.99
20316.69f	0.60	7.31	20693.66f	6.96	7.52	21102.63f	6.30	7.73
20325.73f	9.64	7.07	20695.68f	8.98	7.27	21332.84f	2.44	7.73
20331.59f	5.74	7.82	20696.69f	0.23	7.31	21336.80f	6.40	7.60
20336.68f	1.08	7.31	20708.67f	2.46	7.52	21337.78f	7.38	7.48
20337.71f	2.11	7.42	20709.63f	3.42	7.73	21374.72f	5.31	7.73
20352.58f	7.23	7.48	20719.56f	3.60	7.90	21392.66f	3.74	7.73
20353.65f	8.30	7.31	20720.55f	4.59	7.77	21394.64f	5.72	7.90
20355.61f	0.50	7.19	20749.63f	4.41	7.73	21396.65f	7.73	7.64
20372.68f	7.82	7.44	20756.51f	1.53	7.40	21397.66f	8.62	7.40
20373.57f	8.71	7.13	20960.78f	0.99	7.40	21424.54f	6.36	7.77
20386.57f	2.21	7.40	20992.82f	3.77	7.73	21428.52f	0.59	7.40
20392.57f	8.21	7.52	21009.81f	1.26	7.35	21431.50f	3.57	7.90
20423.54f	0.16	7.27	21010.77f	2.22	7.44	21449.54f	2.10	7.77
20594.88f	5.70	7.90	21016.65f	8.00	7.33	21453.50f	5.76	7.90
20607.76f	8.83	7.44	21021.72f	3.41	7.90	21687.85f	6.34	7.66
20608.82f	0.14	7.16	21022.68f	4.37	7.90	21731.68f	1.41	7.31
20612.84f	4.16	7.77	21025.60f	7.29	7.48	21750.66f	0.88	7.27

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

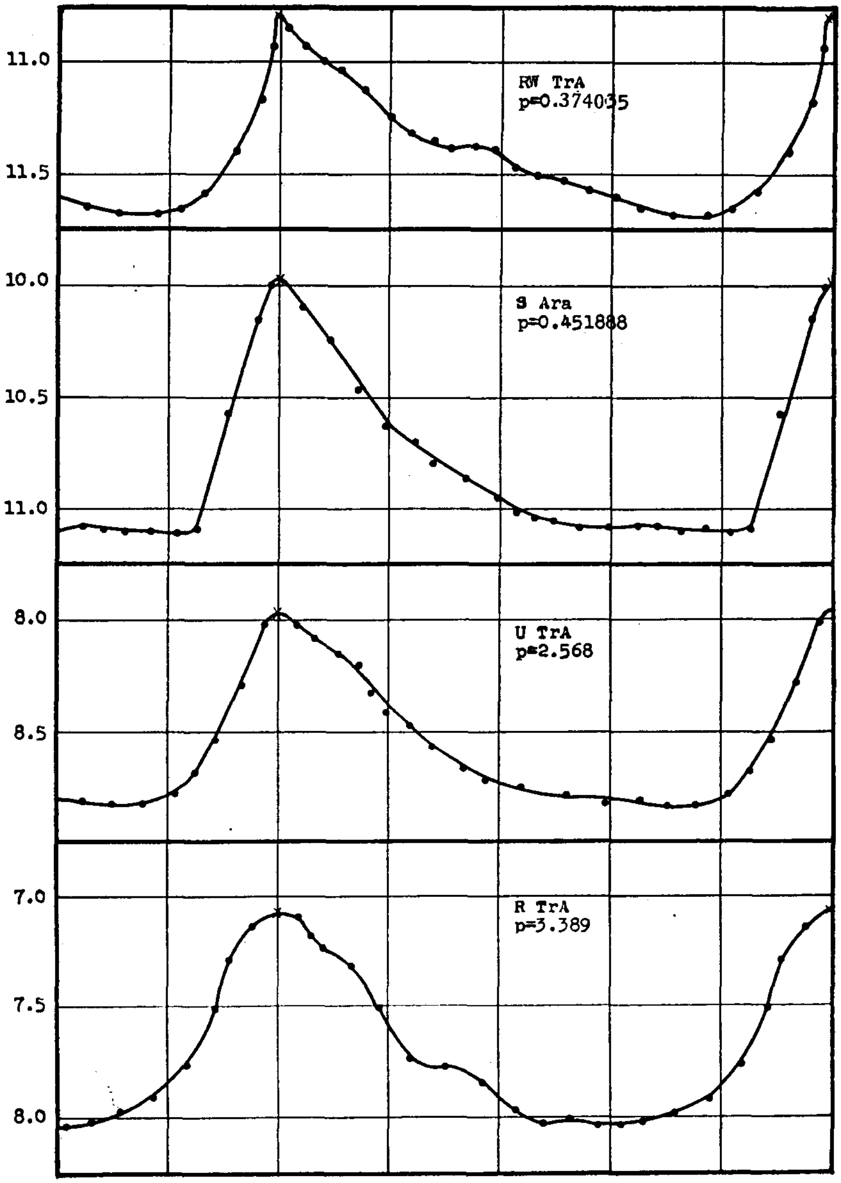
SECTION C

J. D. and	S Nor		J. D. and	S Nor		J. D. and	S Nor	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
21756.68f	6.90	7.73	23193.78f	0.56	7.27	23961.58z	7.63	7.48
21757.67f	7.89	7.54	23194.51f	1.29	7.35	23996.53z	3.57	7.77
21759.65f	0.12	7.19	23197.53f	4.31	7.73	23997.63z	4.67	7.90
21776.58f	7.30	7.64	23199.78f	6.56	7.52	24024.58z	2.36	7.77
21789.54f	0.75	7.31	23219.62f	6.90	7.56	24025.51z	3.29	7.82
21790.54f	1.75	7.40	23219.67f	6.95	7.73	24245.82z	9.04	7.35
21871.51f	4.70	7.77	23221.56f	8.84	7.13	24273.87z	7.83	7.44
21874.52f	7.71	7.64	23222.69f	0.21	7.07	24294.69z	9.14	7.40
22100.65f	9.52	7.13	23233.66f	1.43	7.31	24318.70z	3.89	7.86
22108.62f	7.73	7.64	23250.68f	8.70	7.40	24327.63z	3.07	7.69
22129.52f	9.13	7.31	23267.54f	6.05	7.60	24354.56z	0.74	7.44
22133.59f	3.45	7.73	23268.57f	7.08	7.56	24357.59z	3.77	7.86
22138.54f	8.40	7.35	23533.83f	9.01	7.31	24371.63z	8.06	7.48
22140.60f	0.70	7.19	23575.77f	2.19	7.77	24375.50z	2.18	7.48
22173.52f	4.36	7.82	23576.71f	3.13	7.73	24411.53z	8.95	7.35
22175.56f	6.40	7.73	23610.62f	7.78	7.40	24433.52z	1.68	7.52
22191.54f	2.88	7.73	23647.56f	5.71	7.73	24670.69z	4.78	7.86
22194.51f	5.85	7.82	23648.55f	6.70	7.52	24704.62z	9.45	7.27
22455.70f	3.71	7.73	23673.53f	2.42	7.44	24716.86z	2.18	7.69
22483.72f	2.47	7.64	23902.87z	7.44	7.56	24755.51z	1.82	7.69
22542.60f	2.83	7.69	23941.70z	7.26	7.48	25382.54z	4.86	7.86

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	RW TrA		J. D. and Telescope	RW TrA		J. D. and Telescope	RW TrA	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
11897.723b	0.011	10.91	15519.616f	0.122	11.43	16229.862f	0.076	11.35
12586.819b	.134	11.35	15533.647f	.314	11.62	16241.763b	.008	10.91
13000.738b	.371	10.74	15541.785f	.223	11.55	16254.777f	.305	11.62
13024.617b	.311	11.58	15560.713f	.076	11.43	16286.589b	.324	11.55
13054.594b	.366	11.00	15590.656f	.096	11.26	16310.727f	.149	11.62
13292.770b	.281	11.71	15633.572f	.372	11.00	16311.588f	.262	11.62
13292.801b	.312	11.71	15646.536f	.245	11.62	16338.647f	.017	10.91
13435.533b	.163	11.62	15866.881b	.283	11.63	16359.562f	.360	11.00
13661.775b	.114	11.43	15868.822f	.354	11.00	16360.619b	.295	11.68
14067.802b	.313	11.65	15872.894f	.311	11.65	16379.549f	.149	11.43
14382.799b	.372	10.74	15887.676f	.132	11.43	16582.864f	.363	10.91
14528.593b	.292	11.62	15887.711b	.167	11.43	16593.749f	.027	10.86
14753.806b	.336	11.52	15898.685f	.294	11.65	16604.743f	.174	11.52
14795.733b	.371	10.74	15906.794f	.174	11.43	16605.820b	.129	11.43
14851.516b	.049	11.04	15912.602b	.372	10.82	16605.844f	.153	11.43
14874.641f	.358	11.35	15927.611b	.045	11.00	16607.801f	.239	11.58
14875.550f	.145	11.43	15927.723f	.157	11.43	16625.729f	.214	11.55
15116.877f	.219	11.52	15934.692f	.020	11.00	16636.725f	.363	11.00
15148.681f	.230	11.68	15941.680b	.275	11.65	16650.672f	.096	11.43
15162.693b	.029	10.96	15945.711f	.192	11.43	16653.614f	.046	11.17
15267.530f	.136	11.26	15973.586f	.014	10.91	16667.610f	.203	11.55
15268.657b	.141	11.35	15973.614b	.042	10.96	16680.531f	.033	10.91
15485.879b	.049	11.13	16183.866f	.086	11.35	16697.566f	.236	11.62
15486.749b	.171	11.39	16221.862f	.305	11.62	16745.538f	.332	11.43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11.5
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10.5
11.0
S Ara
p=0.451888
8.0
8.5
U TrA
p=2.568
7.0
7.5
8.0
R TrA
p=3.389

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and	RW TrA		J. D. and	RW TrA		J. D. and	RW TrA	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
16760.556f	0.014	11.00	17704.721f	0.115	11.43	18494.735f	0.167	11.52
16915.897b	.131	11.43	17738.792f	.148	11.62	18507.702f	.042	11.00
16937.880f	.045	10.91	17758.765f	.298	11.62	18533.509f	.041	11.04
16957.797f	.139	11.43	17772.744f	.063	11.26	18804.845f	.201	11.43
16960.760f	.109	11.35	17803.607f	.255	11.68	18856.729f	.095	11.43
16968.749f	.244	11.63	17835.535f	.016	10.82	18868.607b	.003	10.74
16981.830f	.233	11.71	17843.530f	.157	11.52	18897.599f	.195	11.62
17000.777f	.105	11.43	18026.882f	.231	11.65	18898.534b	.008	10.91
17032.815f	.350	11.09	18041.859f	.247	11.65	18917.579f	.351	11.35
17039.564f	.366	11.00	18070.788f	.001	10.91	19166.759b	.050	11.09
17068.608b	.235	11.58	18082.861f	.105	11.43	19177.809f	.252	11.62
17069.621f	.126	11.43	18102.560f	.354	11.35	19180.801f	.252	11.68
17094.587f	.032	10.91	18109.690f	.004	10.78	19239.637f	.365	11.17
17098.615f	.319	11.43	18145.565f	.345	11.26	19290.544f	.029	11.17
17297.844f	.188	11.43	18150.656f	.200	11.43	19301.501f	.139	11.26
17335.760f	.326	11.62	18159.521f	.088	11.35	19312.521f	.312	11.17
17352.829f	.190	11.62	18187.565f	.079	11.26	19569.777f	.232	11.55
17341.784f	.366	10.91	18361.891f	.105	11.26	19634.604f	.351	11.17
17376.803f	.225	11.65	18404.872b	.072	11.17	19903.732f	.173	11.62
17401.717f	.079	11.35	18434.777f	.054	11.00	19942.853f	.021	11.09
17430.654f	.215	11.65	18451.703f	.149	11.62	20287.727f	.034	11.00
17464.556f	.080	11.35	18457.657b	.118	11.43	20313.744f	.243	11.71
17499.522f	.261	11.71	18467.757f	.119	11.43	20316.691f	.198	11.43
17690.807f	.040	10.82	18481.634f	.157	11.62	20336.675f	.358	11.35

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	RW TrA Phase	RW TrA Mag.	J. D. and Telescope	RW TrA Phase	RW TrA Mag.	J. D. and Telescope	RW TrA Phase	RW TrA Mag.
20372.548f	0.323	11.35	21332.840f	0.093	11.30	22191.541f	0.010	10.82
20392.572f	.150	11.47	21336.805f	.318	11.58	22194.510f	.361	11.17
20423.537f	.070	11.17	21337.783f	.174	11.58	22455.704f	.104	11.43
20594.877f	.102	11.35	21374.707f	.068	11.35	22483.720f	.068	11.17
20607.760f	.267	11.65	21392.664f	.072	11.35	22850.619f	.038	11.00
20612.840f	.111	11.39	21397.663f	.208	11.52	23194.509f	.190	11.43
20654.739f	.118	11.43	21424.538f	.153	11.43	23197.529f	.218	11.55
20667.710f	.373	10.91	21428.515f	.015	11.09	23219.673f	.294	11.68
20669.691f	.109	11.35	21431.500f	.008	10.91	23250.678f	.254	11.62
20690.692f	.164	11.43	21449.536f	.090	11.26	23338.537f	.214	11.62
20693.656f	.135	11.35	21687.850f	.144	11.35	23533.859f	.290	11.74
20708.674f	.192	11.65	21731.676f	.208	11.52	23535.733f	.294	11.74
20709.630f	.026	10.95	21756.682f	.154	11.58	23566.838f	.354	11.35
20756.509f	.150	11.62	21757.671f	.021	10.91	23576.710f	.127	11.35
21010.767f	.065	11.35	21776.584f	.232	11.71	23619.643f	.046	11.17
21022.678f	.006	10.74	21789.541f	.098	11.35	23647.557f	.281	11.74
21025.600f	.310	11.62	21790.536f	.345	11.35	23648.549f	.077	11.43
21037.631f	.372	10.91	22100.654f	.013	11.00	23671.519f	.305	11.74
21038.587f	.206	11.52	22108.620f	.125	11.47	23692.537f	.003	11.00
21047.717f	.359	11.21	22129.515f	.074	11.43	23902.869z	.127	11.26
21078.543f	.140	11.43	22133.593f	.037	11.09	23914.782z	.071	11.17
21080.546f	.273	11.65	22140.595f	.307	11.65	23940.713z	.194	11.43
21081.541f	.146	11.58	22173.520f	.317	11.58	23941.701z	.060	11.09
21102.633f	.292	11.62	22175.561f	.113	11.43	23961.581z	.116	11.35

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	RW TrA		J. D. and Telescope	RW TrA		J. D. and Telescope	RW TrA	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
23962.638z	0.051	11.17	24075.522z	0.350	11.43	24371.634z	0.227	11.55
23972.691z	.005	11.00	24245.820z	.088	11.43	24375.502z	.354	11.26
23996.531z	.281	11.74	24273.870z	.086	11.17	24433.522z	.025	11.09
23997.574z	.202	11.65	24318.703z	.034	11.17	24648.700z	.133	11.35
23997.632z	.260	11.74	24326.690z	.167	11.62	24670.694z	.058	11.17
24021.609z	.298	11.71	24327.630z	.359	11.26	24704.621z	.322	11.62
24024.576z	.273	11.65	24356.562z	.116	11.43	24716.859z	.217	11.55
24025.510z	.085	11.17	24357.589z	.021	11.21	25382.539z	.115	11.26

J. D. and Telescope	BF Oph		J. D. and Telescope	BF Oph		J. D. and Telescope	BF Oph	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
14757.84e	1.64	8.19	15148.73f	2.01	8.39	15842.81f	0.46	7.82
14812.70e	3.62	8.19	15191.61e	0.14	7.71	15842.87e	0.52	7.82
14861.59f	3.69	8.09	15517.75e	0.84	7.93	15872.72f	1.89	8.24
14862.62f	0.66	7.93	15527.68f	2.63	8.44	15872.81f	1.98	8.44
14874.55e	0.38	7.82	15532.66f	3.54	8.19	15873.81e	2.98	8.49
14892.58e	2.14	8.34	15532.70f	3.58	8.04	15879.76f	0.79	7.82
14904.52f	1.88	8.24	15540.69e	3.44	8.39	15885.83f	2.79	8.49
14904.57f	1.93	8.44	15543.71f	2.39	8.44	15896.73e	1.49	8.24
14928.52f	1.47	8.29	15551.69f	2.23	8.39	15897.61f	2.37	8.34
15108.88f	2.84	8.29	15591.58f	1.44	8.24	15897.70f	2.46	8.49
15116.83e	2.65	8.49	15609.60f	3.19	8.44	15898.73e	3.49	8.29
15119.82e	1.57	8.29	15613.57e	3.09	8.34	15911.72f	0.21	7.49
15147.69f	0.97	8.09	15634.57f	3.76	8.19	15914.54f	3.03	8.49

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	BF Oph		J. D. and Telescope	BF Oph		J. D. and Telescope	BF Oph	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
15925.61f	1.89	8.44	16279.80f	2.17	8.39	16608.84f	1.70	8.14
15927.63f	3.91	7.60	16282.66e	0.96	8.14	16608.89f	1.75	8.44
15932.65e	0.80	8.14	16288.73f	2.96	8.39	16613.75e	2.54	8.54
15933.68f	1.83	8.39	16295.58f	1.68	8.39	16625.69f	2.28	8.44
15934.65f	2.80	8.44	16297.69f	3.79	7.93	16634.67f	3.12	8.39
15940.64f	0.65	7.93	16298.65f	0.68	7.71	16636.77f	1.15	7.93
15943.62e	3.63	8.19	16311.63f	1.45	8.39	16638.65f	3.03	8.34
15956.65f	0.39	7.60	16319.54f	1.23	8.09	16642.68e	2.99	8.54
16008.53f	3.45	8.34	16323.63f	1.25	7.98	16644.68e	0.92	7.98
16023.57f	2.22	8.49	16337.61f	3.03	8.54	16644.67f	0.93	7.93
16224.86e	0.11	7.82	16339.61f	0.96	7.93	16650.72f	2.90	8.49
16226.76f	2.01	8.34	16359.61f	0.62	7.82	16650.76f	2.94	8.44
16226.82e	2.07	8.39	16372.55f	1.35	8.19	16663.80f	3.77	7.82
16229.77f	0.95	8.24	16376.53f	1.27	7.93	16664.66f	0.57	7.82
16240.63f	3.67	7.93	16376.62f	1.36	8.39	16668.72f	0.56	7.82
16241.73f	0.71	7.82	16558.83f	0.51	7.82	16683.52f	3.15	8.44
16242.70f	1.68	8.14	16582.77f	0.04	7.60	16691.57f	3.07	8.34
16253.62f	0.40	7.60	16589.77f	2.97	8.59	16691.62f	3.12	8.54
16253.71f	0.49	7.93	16591.70f	0.83	8.29	16694.63f	2.06	8.39
16257.73e	0.44	7.60	16593.70f	2.83	8.44	16697.67f	1.03	8.14
16259.72e	2.43	8.54	16593.79f	2.92	8.49	16707.59f	2.82	8.44
16260.73e	3.44	8.44	16604.83f	1.76	8.24	16743.54f	3.15	8.44
16264.71f	3.35	8.34	16606.72f	3.65	8.19	16918.81f	2.50	8.59
16268.73f	3.30	8.34	16608.80f	1.66	8.34	16922.80f	2.42	8.54

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	BF Oph		J. D. and Telescope	BF Oph		J. D. and Telescope	BF Oph	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
16934.87f	2.29	8.59	17034.63e	0.35	7.82	17403.63f	3.23	8.44
16935.87e	3.29	8.29	17075.57f	0.61	7.93	17403.72f	3.32	8.49
16938.83f	2.18	8.44	17076.67f	1.71	8.44	17404.62f	0.15	7.71
16939.85e	3.20	8.44	17077.56f	2.60	8.54	17408.62e	0.08	7.82
16943.84f	3.12	8.44	17077.65f	2.69	8.44	17430.57f	1.69	8.34
16944.86e	0.07	7.49	17097.54f	2.24	8.34	17431.57f	2.69	8.39
16960.80f	3.81	7.82	17105.61f	2.17	8.44	17437.56e	0.54	7.82
16968.80f	3.67	8.24	17107.57f	0.06	7.60	17445.55f	0.40	7.82
16972.84f	3.65	8.14	17241.88f	0.13	7.82	17447.57f	2.42	8.39
16976.74f	3.48	8.24	17319.82e	0.78	7.93	17448.52f	3.37	8.34
16979.69f	2.36	8.39	17325.80f	2.69	8.44	17465.52f	0.03	7.71
16979.77f	2.44	8.49	17329.72f	2.54	8.59	17465.57f	0.08	7.65
16988.74f	3.27	8.44	17335.67f	0.35	7.60	17482.52f	0.76	7.93
16988.79f	3.32	8.34	17335.80f	0.48	7.71	17495.54f	1.57	8.39
16989.73e	0.20	7.71	17343.82f	0.37	7.71	17686.81f	1.65	8.49
16991.77f	2.24	8.34	17360.73f	1.01	8.29	17703.90f	1.46	8.44
16999.69f	2.02	8.34	17371.74f	3.88	7.93	17705.85f	0.35	7.82
17004.61f	2.87	8.59	17372.67e	0.74	7.93	17713.64f	0.00	7.60
17004.65f	2.92	8.49	17374.70f	2.77	8.44	17718.77f	1.06	8.19
17009.68f	3.87	7.60	17375.69e	3.76	7.82	17719.66f	1.95	8.34
17009.77f	3.96	7.82	17376.72f	0.72	8.19	17719.76f	2.05	8.44
17021.77f	3.76	8.04	17377.70f	1.70	8.39	17725.71f	3.93	7.60
17032.64f	2.43	8.34	17384.72f	0.59	8.14	17730.52f	0.61	8.04
17032.77f	2.56	8.44	17402.63f	2.23	8.34	17730.74f	0.83	7.82

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	BF Oph	
	Phase	Mag.
17758.68f	0.29	7.82
17759.62f	1.23	8.14
17762.63e	0.17	7.82
17772.65f	2.06	8.29
17774.72f	0.06	7.60
17784.62e	1.82	8.29
17787.64f	0.78	8.11
17793.63f	2.70	8.44
17802.55f	3.48	8.34
17803.55e	0.41	8.04
17813.55f	2.28	8.44
17814.52f	3.25	8.34
17820.55f	1.14	8.29
18015.82f	1.15	8.19
18026.80f	3.99	7.82
18027.89f	1.01	8.29
18033.85f	2.90	8.44
18034.82e	3.87	7.82
18040.81f	1.73	8.29
18042.86f	3.78	7.82
18056.75f	1.40	8.34
18063.79e	0.30	7.60
18068.82f	1.26	8.29
18069.81f	2.25	8.39
18069.86f	2.30	8.39
18081.67f	1.91	8.34
18097.77f	1.74	8.39
18100.68f	0.58	7.93
18100.72f	0.62	8.09
18103.70e	3.60	8.24
18111.78f	3.54	8.19
18115.58f	3.27	8.44
18123.68e	3.24	8.39
18126.52f	2.01	8.34
18145.61f	0.76	7.82
18148.59f	3.74	7.82
18148.66f	3.81	7.71
18150.57f	1.65	8.29
18156.61f	3.62	8.24
18157.56f	0.51	8.09
18168.56f	3.37	8.34
18174.57f	1.24	8.29
18183.57f	2.11	8.39
18199.56f	1.83	8.34
18209.53f	3.66	8.19
18361.84f	1.39	8.29
18392.79f	3.86	7.82
18394.81f	1.81	8.54
18395.83f	2.83	8.49
18396.85f	3.85	7.71
18414.85f	1.46	8.34
18421.81e	0.34	7.82
18422.75f	1.28	8.24
18423.81e	2.34	8.49
18435.77f	2.09	8.44
18438.68e	0.93	8.09
18438.80e	1.05	8.19
18438.84f	1.09	8.24
18440.69f	2.94	8.44
18453.80f	3.85	7.93
18454.78f	0.76	8.09
18456.71f	2.69	8.54
18466.70e	0.48	7.82
18467.67f	1.45	8.24
18467.71f	1.49	8.29
18471.75f	1.46	8.29
18472.69f	2.40	8.44
18474.70e	0.34	7.71
18477.70f	3.34	8.29
18479.65f	1.22	8.19
18481.68f	3.25	8.44
18495.69f	0.99	8.14

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and	BF Oph		J. D. and	BF Oph		J. D. and	BF Oph	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
18498.61f	3.91	7.93	18820.82f	0.68	7.87	18912.53f	2.89	8.39
18499.71f	0.94	8.14	18821.79f	1.65	8.39	18917.51f	3.81	7.82
18500.63f	1.86	8.29	18822.73f	2.59	8.39	18918.52f	0.75	8.09
18500.72f	1.95	8.39	18827.70f	3.49	8.39	18919.55f	1.78	8.39
18501.59f	2.82	8.49	18827.76f	3.55	8.24	19137.85f	0.41	7.71
18503.61f	0.78	8.14	18830.73e	2.45	8.54	19153.79f	0.07	7.60
18506.68f	3.85	8.04	18831.68f	3.40	8.34	19159.81f	2.03	8.29
18507.60e	0.70	7.93	18832.78f	0.44	7.93	19184.73e	2.54	8.44
18509.61f	2.71	8.39	18848.63f	0.01	7.71	19191.67e	1.34	8.29
18510.60f	3.70	8.09	18849.70f	1.08	8.29	19204.62f	2.09	8.39
18514.67f	3.60	8.19	18852.70e	0.02	7.60	19204.65f	2.12	8.39
18514.62f	3.65	8.14	18855.66f	2.98	8.44	19204.74f	2.21	8.34
18524.52f	1.35	8.19	18855.75f	3.07	8.46	19205.65f	3.12	8.44
18531.56f	0.25	7.82	18858.62f	1.87	8.29	19213.63f	2.96	8.54
18531.61f	0.30	7.71	18859.60e	2.85	8.44	19219.64e	0.84	7.93
18535.56f	0.18	7.82	18859.65f	2.90	8.44	19231.52f	0.51	8.09
18565.53f	1.68	8.39	18859.70f	2.95	8.49	19232.53f	1.52	8.34
18752.85e	1.87	8.34	18862.61f	1.79	8.34	19233.62f	2.61	8.44
18766.88f	3.69	8.09	18862.66f	1.84	8.24	19233.66f	2.65	8.49
18774.85e	3.53	8.39	18866.59f	1.70	8.29	19235.61f	0.53	7.82
18797.79f	2.06	8.29	18878.64f	1.55	8.29	19237.63f	2.55	8.39
18811.78e	3.84	7.71	18884.63f	3.47	8.39	19240.60f	1.46	8.19
18819.72f	3.65	8.14	18887.59f	2.36	8.39	19241.61f	2.47	8.44
18820.77f	0.63	7.93	18908.54f	2.97	8.59	19250.56f	3.28	8.29

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and	BF Oph		J. D. and	BF Oph		J. D. and	BF Oph	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
19264.60f	1.05	8.24	19545.81f	1.56	8.39	19632.53f	2.86	8.44
19267.56f	4.01	7.82	19557.74e	1.29	8.19	19632.58f	2.91	8.46
19271.55e	3.93	7.65	19560.67f	0.15	7.76	19634.56f	0.82	8.09
19288.50f	0.54	7.71	19561.72f	1.20	8.14	19643.49f	1.61	8.44
19291.51f	3.55	8.19	19561.77f	1.25	8.19	19644.56f	2.68	8.39
19300.50f	0.34	7.71	19562.69f	2.17	8.39	19645.56f	3.68	8.19
19302.51f	2.35	8.34	19566.61f	2.02	8.39	19645.63f	3.75	8.14
19304.49f	0.26	7.82	19568.66f	0.01	7.60	19648.53f	2.58	8.44
19311.53f	3.23	8.44	19568.70f	0.05	7.71	19650.57f	0.56	8.09
19487.88e	0.59	7.71	19572.70f	4.05	7.76	19650.65f	0.64	7.71
19510.76f	3.13	8.49	19589.69f	0.70	8.04	19657.56f	3.48	8.34
19511.78f	0.08	7.82	19592.64f	3.65	7.93	19688.52f	1.89	8.24
19513.83e	2.13	8.44	19593.66f	0.60	8.04	19865.87e	0.25	7.82
19517.78f	2.01	8.44	19593.71f	0.65	7.71	19889.83f	3.87	7.71
19518.78f	3.01	8.44	19599.64f	2.51	8.44	19889.88f	3.92	7.82
19520.83e	0.99	7.93	19601.60f	0.40	7.87	19895.81f	1.72	8.39
19532.72f	0.68	7.93	19601.64f	0.44	7.87	19898.82f	0.66	7.93
19534.69f	2.65	8.54	19603.61f	2.41	8.49	19898.87f	0.71	7.82
19534.77f	2.73	8.44	19603.65f	2.45	8.44	19911.80f	1.43	8.19
19541.79f	1.61	8.24	19604.55f	3.35	8.39	19911.85f	1.48	8.44
19542.85f	2.67	8.44	19615.58f	2.18	8.39	19912.76f	2.39	8.34
19544.71f	0.46	7.82	19616.53f	3.13	8.49	19912.80f	2.43	8.44
19544.77f	0.52	7.93	19616.58f	3.18	8.59	19917.73e	3.30	8.39
19545.76f	1.51	8.24	19620.57f	3.10	8.39	19921.75e	3.25	8.44

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and	BF Oph		J. D. and	BF Oph		J. D. and	BF Oph	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
19921.77f	3.27	8.54	19982.54f	3.02	8.54	20307.67f	2.71	8.39
19922.82f	0.25	7.87	19985.52f	1.93	8.49	20308.66f	3.70	8.09
19925.69f	3.12	8.54	19989.52f	1.86	8.44	20309.65e	0.62	7.71
19926.72f	0.08	7.71	19998.57f	2.78	8.54	20314.70f	1.60	8.34
19930.60f	3.96	7.71	20012.57f	0.50	7.87	20327.59f	2.29	8.39
19930.69f	4.05	7.71	20013.56f	1.49	8.29	20327.64f	2.34	8.44
19931.66f	0.95	8.09	20020.52f	0.32	7.82	20328.60f	3.30	8.39
19942.66f	3.82	7.82	20027.51f	3.24	8.39	20329.69f	0.32	7.82
19942.76f	3.92	7.71	20029.51f	1.17	8.09	20330.60f	1.23	8.19
19943.75f	0.84	8.09	20037.52f	1.05	8.09	20330.67f	1.30	8.44
19944.67f	1.76	8.39	20044.52f	3.98	7.82	20332.63e	3.26	8.44
19947.66e	0.68	7.93	20044.56f	4.02	7.82	20337.66f	0.15	7.71
19947.72f	0.74	7.87	20276.76e	0.28	7.82	20338.58f	1.07	8.19
19950.71f	3.73	7.82	20280.76e	0.20	7.71	20338.62f	1.11	8.19
19951.68f	0.63	8.04	20287.59f	2.97	8.44	20354.58f	0.80	7.93
19951.72f	0.67	8.04	20287.64f	3.02	8.39	20357.54f	3.76	7.82
19953.63f	2.58	8.49	20296.67f	3.91	7.82	20357.60f	3.82	7.65
19959.58f	0.40	7.60	20297.67f	0.84	8.09	20365.54f	3.62	7.82
19961.60f	2.42	8.34	20301.67e	0.77	7.93	20365.60f	3.68	7.93
19971.61f	0.22	7.82	20303.68f	2.78	8.44	20366.58f	0.60	7.93
19973.51f	2.12	8.44	20303.73f	2.83	8.49	20367.59f	1.61	8.44
19976.57f	1.12	8.09	20306.65f	1.69	8.24	20369.55f	3.57	8.14
19976.61f	1.16	8.14	20306.74f	1.74	8.34	20370.55f	0.50	8.09
19977.67f	2.22	8.47	20307.56f	2.60	8.46	20372.62f	2.57	8.44

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and	BF Oph		J. D. and	BF Oph		J. D. and	BF Oph	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
20384.53f	2.27	8.49	20656.63f	1.82	8.49	20712.53f	0.77	7.93
20386.52f	0.20	7.71	20657.69e	2.88	8.54	20719.61f	3.78	7.82
20388.55f	2.23	8.44	20659.72f	0.84	7.87	20720.59f	0.69	8.09
20391.54f	1.15	8.34	20660.73f	1.85	8.39	20747.52f	3.21	8.54
20393.53f	3.14	8.44	20667.77f	0.75	8.04	20750.81f	2.43	8.34
20394.58f	0.12	7.71	20668.72f	1.70	8.29	20752.48f	0.04	7.71
20414.54f	3.81	7.82	20669.64f	2.62	8.44	20769.48f	0.76	7.93
20415.54f	0.74	7.82	20670.62f	3.60	7.98	20776.49f	3.70	7.93
20568.89e	3.57	8.14	20670.66f	3.64	7.93	20964.84e	0.86	8.19
20580.87f	3.35	8.29	20681.65f	2.43	8.44	20991.77f	3.38	8.19
20600.85e	2.99	8.34	20681.71f	2.49	8.49	20992.72f	0.26	7.82
20605.86f	3.93	7.82	20683.67f	0.38	7.93	20993.73e	1.27	8.14
20610.81f	0.75	8.09	20685.63e	2.34	8.39	20994.75f	2.29	8.34
20610.85f	0.79	8.19	20688.66f	1.30	8.29	20994.80f	2.34	8.34
20624.73e	2.46	8.54	20688.71f	1.35	8.44	21006.79f	2.13	8.52
20624.80f	2.53	8.44	20690.60f	3.24	8.34	21007.71f	3.05	8.39
20627.72e	1.38	8.29	20691.58f	0.16	7.82	21007.78f	3.12	8.49
20628.79f	2.45	8.44	20691.62f	0.20	7.71	21009.78f	1.05	8.24
20650.76e	0.02	7.82	20693.61f	2.19	8.44	21009.83f	1.10	8.09
20652.69f	1.95	8.34	20695.62f	0.13	7.82	21011.69f	2.96	8.44
20652.77f	2.03	8.44	20695.66f	0.17	7.82	21011.76f	3.03	8.49
20653.76f	3.02	8.44	20695.68f	0.19	7.71	21012.65f	3.92	7.82
20654.78f	4.04	7.82	20708.55f	0.85	8.09	21012.67f	3.94	7.82
20655.66f	0.85	7.93	20710.53f	2.83	8.54	21013.67f	0.87	8.09

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and	BF Oph		J. D. and	BF Oph		J. D. and	BF Oph	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
21013.71f	0.91	8.29	21079.59f	1.70	8.39	21365.70f	3.05	8.49
21021.67f	0.74	8.09	21080.60f	2.71	8.44	21370.75f	4.04	7.87
21022.72f	1.79	8.54	21091.55e	1.46	8.34	21372.74f	1.96	8.44
21023.70f	2.77	8.39	21092.54f	2.45	8.54	21391.70f	0.58	7.82
21023.74f	2.81	8.49	21093.54f	3.45	8.24	21393.65f	2.53	8.39
21025.69f	0.69	7.93	21099.55f	1.32	8.29	21393.75f	2.63	8.44
21026.63f	1.63	8.24	21103.55f	1.25	8.19	21394.68f	3.56	8.29
21035.63e	2.49	8.49	21127.51f	0.81	8.14	21395.62f	0.43	7.82
21035.64f	2.50	8.44	21134.49f	3.72	7.93	21397.70e	2.51	8.44
21044.55f	3.28	8.39	21135.52f	0.68	8.09	21398.62f	3.43	8.24
21044.67e	3.40	8.44	21137.53f	2.69	8.49	21398.66f	3.47	8.34
21045.58f	0.24	7.82	21153.48f	2.37	8.29	21398.70f	3.51	8.19
21047.63f	2.29	8.54	21155.49f	0.31	8.04	21399.61f	0.35	8.09
21048.60f	3.26	8.39	21156.51f	1.33	8.24	21400.67f	1.41	8.29
21048.68f	3.34	8.44	21160.50f	1.25	8.19	21403.67f	0.34	7.82
21049.63f	0.22	8.09	21313.86e	0.03	7.82	21407.68e	0.29	7.82
21050.59f	1.18	8.19	21316.84f	3.01	8.54	21421.58f	1.98	8.44
21062.59f	0.98	8.24	21333.84f	3.74	7.71	21424.63f	0.96	8.14
21062.63f	1.02	8.34	21335.84f	1.67	8.14	21425.68f	2.01	8.39
21063.63f	2.02	8.44	21337.83f	3.66	7.98	21426.54f	2.87	8.59
21066.59f	0.91	8.29	21360.72e	2.14	8.54	21426.59f	2.92	8.44
21066.63f	0.95	8.24	21361.76f	3.18	8.54	21427.54f	3.87	7.82
21077.55f	3.73	7.93	21363.75f	1.10	8.09	21427.62f	3.95	7.82
21079.54f	1.65	8.39	21364.83f	2.18	8.49	21428.65f	0.92	7.93

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	BF Oph		J. D. and Telescope	BF Oph		J. D. and Telescope	BF Oph	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
21429.66f	1.93	8.34	21806.58f	0.52	7.82	22551.54f	1.03	8.04
21450.55f	2.48	8.49	21806.66f	0.60	8.09	22552.50f	1.99	8.44
21451.53f	3.46	8.34	21844.52f	1.85	8.24	22574.51f	3.66	7.93
21452.52f	0.38	7.71	21866.49f	3.48	8.19	22580.51f	1.53	8.34
21457.56f	1.35	8.14	22070.78e	0.30	8.04	22581.51f	2.53	8.59
21516.50f	3.34	8.39	22071.83e	1.35	8.29	22767.85e	1.74	8.39
21663.90e	0.22	7.60	22097.67e	2.78	8.39	22821.75e	2.76	8.59
21715.82e	3.32	8.29	22131.61f	0.11	7.60	22843.73e	0.33	7.71
21716.75f	0.19	7.71	22132.62f	1.12	8.19	22854.71f	3.17	8.39
21731.72f	2.95	8.44	22135.64f	0.07	7.82	22868.65f	0.84	8.24
21748.63e	3.59	7.93	22136.59f	1.02	8.09	22905.59f	1.17	8.24
21749.71f	0.60	8.09	22138.60f	3.03	8.44	23122.87q	2.84	8.54
21751.70f	2.59	8.59	22138.67e	3.10	8.44	23143.88q	3.51	7.93
21755.70f	2.52	8.44	22142.55f	2.91	8.59	23166.79q	2.01	8.39
21757.71f	0.47	7.93	22165.54f	1.50	8.14	23169.83q	0.99	7.93
21760.64f	3.40	8.34	22166.51f	2.47	8.39	23172.79e	3.95	7.60
21760.69f	3.45	7.93	22171.53f	3.42	8.09	23172.84f	4.00	7.60
21777.60f	0.02	7.82	22187.54f	3.15	8.29	23175.77q	2.86	8.54
21783.59f	1.94	8.49	22192.31f	3.86	7.71	23175.84e	2.93	8.39
21786.60f	0.88	8.19	22225.53f	0.46	7.93	23176.68f	3.77	7.60
21788.63f	2.91	8.39	22458.76f	1.82	8.54	23180.86f	3.88	7.82
21789.59f	3.87	7.71	22516.60f	2.71	8.44	23181.82f	0.77	8.19
21804.58f	2.59	8.34	22517.55f	3.66	7.82	23190.76q	1.58	8.39
21805.53f	3.54	8.14	22541.57f	3.27	8.49	23194.75f	1.50	8.19

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and	BF Oph		J. D. and	BF Oph		J. D. and	BF Oph	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
23194.82q	1.57	8.39	23306.51f	3.42	8.34	23645.61q	0.81	7.93
23197.76q	0.43	7.93	23311.52f	0.30	7.82	23662.53f	1.46	8.24
23198.73f	1.41	8.09	23311.52q	0.30	7.93	23664.51f	3.44	8.19
23198.77f	1.45	8.29	23346.52f	2.75	8.54	23664.56f	3.49	8.34
23203.72q	2.33	8.44	23474.90e	0.96	8.19	23901.87z	0.78	7.93
23204.72e	3.33	8.19	23498.77q	0.42	7.93	23905.83z	0.68	7.93
23205.65f	0.19	7.82	23535.65f	0.69	7.82	23912.78z	3.56	7.93
23206.69f	1.23	8.14	23535.69f	0.73	7.93	23919.73z	2.37	8.39
23209.72f	0.20	7.82	23535.78f	0.82	7.93	23919.79z	2.43	8.39
23222.72f	0.99	8.09	23546.78e	3.68	7.82	23934.68z	1.05	8.24
23225.70f	3.97	7.71	23561.73f	2.36	8.39	23937.70q	0.00	7.60
23228.66q	2.86	8.39	23563.77q	0.33	7.93	23947.68z	1.85	8.39
23230.64q	0.78	7.93	23573.69f	2.11	8.39	23947.76q	1.93	8.29
23235.62f	1.69	8.14	23576.78f	1.13	8.24	23960.58z	2.54	8.39
23237.59f	3.66	7.82	23581.68q	1.97	8.39	23965.63z	3.52	8.09
23239.67f	1.67	8.49	23587.59z	3.81	7.71	23965.71z	3.60	8.39
23247.66f	1.52	8.24	23587.67q	3.89	7.93	23967.56z	1.39	8.19
23257.60q	3.33	8.19	23588.67e	0.82	8.14	23969.70z	3.53	8.44
23258.59f	0.25	7.71	23601.63e	1.58	8.39	23969.88z	3.71	7.93
23261.53f	3.22	8.34	23614.62e	2.36	8.54	23974.68q	0.37	8.04
23262.62f	0.21	7.82	23615.56f	3.30	8.34	23985.59e	3.14	8.54
23276.60f	1.99	8.49	23616.51f	0.18	7.71	23993.64z	3.06	8.39
23277.57f	2.96	8.49	23639.51f	2.84	8.34	24018.49z	3.50	8.14
23283.72f	0.97	8.09	23641.60f	0.87	7.93	24023.58z	0.45	7.87

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	BF Oph		J. D. and Telescope	BF Oph		J. D. and Telescope	BF Oph	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
24026.52z	3.39	8.19	24348.62z	0.05	7.71	24786.53z	2.69	8.59
24033.52z	2.26	8.34	24373.56z	0.58	8.14	25037.73q	1.67	8.54
24033.57z	2.31	8.34	24399.53z	2.15	8.24	25062.68q	2.21	8.39
24044.52z	1.05	8.19	24404.52z	3.07	8.34	25306.60z	2.05	8.39
24232.86q	2.27	8.49	24432.53z	2.60	8.39	25327.58z	2.69	8.54
24241.84e	3.11	8.54	24623.78z	2.66	8.34	25330.59z	1.63	8.29
24243.85z	1.05	8.19	24640.79e	3.39	8.19	25352.73q	3.43	8.24
24256.80q	1.80	8.19	24641.77z	0.31	7.71	25353.85r	0.48	7.93
24256.82e	1.82	8.34	24646.77z	1.24	8.24	25354.77r	1.40	8.39
24275.74q	0.40	8.14	24656.72e	3.05	8.47	25354.85q	1.48	8.39
24285.69z	2.21	8.29	24656.75q	3.08	8.49	25355.54z	2.17	8.54
24285.79z	2.31	8.44	24676.66q	2.65	8.54	25355.60z	2.23	8.39
24289.79z	2.24	8.39	24678.74q	0.66	7.93	25379.78q	2.01	8.44
24292.76z	1.14	8.19	24679.61z	1.53	8.34	25386.35z	0.44	8.09
24298.68z	3.00	8.39	24682.67z	0.53	8.14	25388.44z	2.53	8.63
24300.80z	1.05	8.09	24683.67q	1.53	8.19	25389.60z	3.69	7.93
24301.77q	2.02	8.54	24695.59e	1.24	8.29	25408.67r	2.42	8.34
24314.64z	2.68	8.29	24697.67e	3.32	8.24	25410.40z	0.08	7.71
24314.74q	2.78	8.44	24731.57z	0.61	8.19	25415.66r	1.27	8.04
24314.74e	2.78	8.49	24731.64z	0.68	7.71	25417.41z	3.02	8.29
24315.70e	3.74	7.82	24734.55z	3.59	7.93	25473.56r	2.22	8.39
24317.65z	1.63	8.34	24738.57z	3.54	8.04	25680.91r	2.10	8.54
24318.65q	2.63	8.29	24753.52z	2.22	8.54	25735.75r	4.06	7.82
24326.63z	2.47	8.44	24770.53q	2.96	8.44	25739.77e	4.01	7.71

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and	BF Oph		J. D. and	BF Oph		J. D. and	BF Oph	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
25748.73r	0.77	8.09	25790.64e	2.00	8.39	25826.60e	1.34	8.04
25764.72r	0.48	7.82	25792.66r	4.02	7.71	25829.58r	0.26	7.82
25765.68e	1.44	8.34						

J. D. and	S Ara		J. D. and	S Ara		J. D. and	S Ara	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
14863.643f	0.002	10.34	15941.690f	0.300	11.05	16653.614f	0.051	10.68
14925.521f	.423	10.01	15943.562f	.364	11.05	16667.610f	.038	10.34
14927.571f	.214	11.15	15945.711f	.254	11.09	16685.619f	.424	10.01
15148.681f	.351	11.02	16008.577f	.307	10.98	16697.566f	.170	11.02
15235.654f	.110	10.79	16183.866f	.265	11.09	16706.601f	.167	10.79
15267.530f	.354	11.09	16254.777f	.229	11.15	16726.596f	.279	11.02
15274.575f	.169	11.11	16297.647f	.170	11.05	16745.538f	.242	11.15
15519.616f	.287	11.11	16302.659f	.211	11.05	16915.890f	.232	11.05
15533.647f	.311	11.05	16310.727f	.146	10.79	16957.797f	.114	10.68
15590.656f	.382	10.58	16311.588f	.103	10.79	16960.760f	.366	11.02
15633.572f	.368	10.85	16359.562f	.177	10.85	16968.749f	.221	11.05
15646.540f	.232	11.09	16379.550f	.282	11.09	16981.830f	.197	11.09
15872.894f	.191	11.09	16593.749f	.286	11.09	17000.777f	.165	10.96
15887.676f	.060	10.34	16604.743f	.435	9.95	17032.815f	.119	10.96
15898.685f	.224	11.07	16607.801f	.330	11.02	17039.564f	.089	10.74
15934.692f	.080	10.79	16636.725f	.334	11.09	17094.587f	.434	10.01
15940.551f	.064	10.68	16650.672f	.272	11.09	17297.844f	.076	11.15

TABLE IV.—Photographic Observations of Cepheid Variable Stars.—*Cont.*

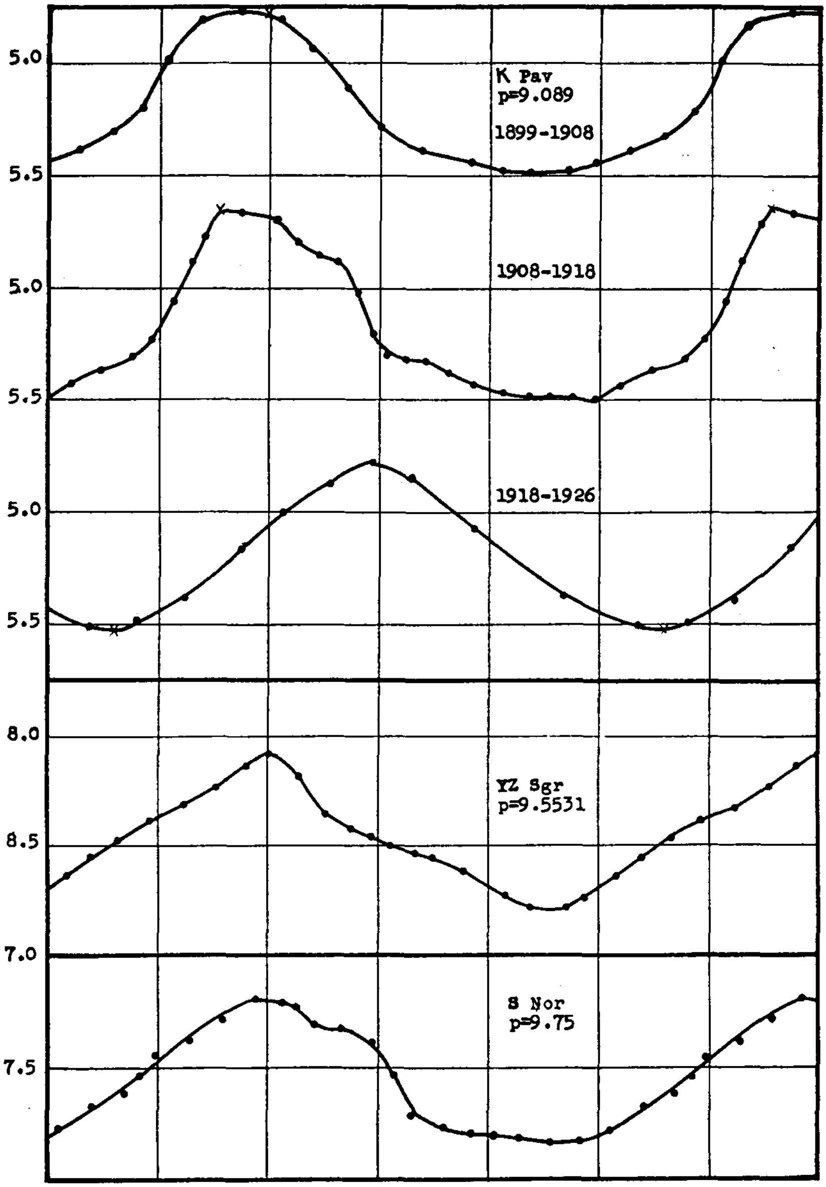
Section C

J. D. and	S Ara		J. D. and	S Ara		J. D. and	S Ara	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
17335.760f	0.342	11.09	18434.777f	0.327	11.09	19290.544f	0.218	10.96
17352.829f	.197	10.96	18444.768f	.376	11.02	19301.501f	.330	11.09
17376.803f	.221	11.02	18451.703f	.081	10.68	19312.521f	.053	10.24
17401.717f	.281	11.09	18467.757f	.319	11.02	19323.520f	.207	11.09
17430.654f	.297	11.05	18481.634f	.187	11.02	19540.846f	.325	11.05
17464.556f	.308	11.05	18494.735f	.184	11.02	19548.803f	.449	9.95
17499.522f	.026	10.06	18498.694f	.076	10.68	19560.720f	.165	10.79
17704.721f	.068	10.58	18538.506f	.121	10.74	19569.777f	.185	10.85
17738.792f	.248	11.09	18791.805f	.363	11.07	19575.687f	.220	10.98
17758.765f	.338	11.09	18832.672f	.108	10.63	19595.706f	.356	10.96
17772.744f	.309	11.05	18860.714f	.133	10.85	19599.691f	.274	11.02
17803.607f	.443	10.01	18917.579f	.060	10.46	19634.604f	.392	10.85
18026.882f	.034	10.17	19177.809f	.004	10.01	19648.568f	.347	11.02
18041.859f	.098	10.74	19180.801f	.284	11.00	19902.841f	.207	11.02
18070.788f	.107	10.79	19196.773f	.440	10.19	19903.732f	.194	11.04
18082.861f	.431	10.06	19203.760f	.197	11.09	19917.791f	.245	10.96
18109.690f	.146	10.96	19213.714f	.209	11.04	19930.648f	.449	10.06
18145.565f	.322	11.11	19220.751f	.016	10.17	19942.853f	.001	10.01
18150.656f	.442	10.17	19224.691f	.341	11.07	19945.750f	.187	10.96
18159.521f	.270	11.05	19234.630f	.339	11.15	19952.644f	.302	10.85
18187.565f	.297	11.07	19235.570f	.375	11.15	19971.677f	.356	11.05
18190.548f	.116	10.79	19239.637f	.375	11.09	19987.526f	.389	11.15
18361.891f	.195	10.96	19250.647f	.088	10.58	20012.525f	.082	10.52
18422.815f	.114	10.74	19254.630f	.004	10.01	20047.615f	.377	10.79

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and	S Ara		J. D. and	S Ara		J. D. and	S Ara	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
20282.800f	0.128	10.74	20669.690f	0.202	11.11	21078.543f	0.096	10.58
20287.727f	.084	10.52	20681.742f	.053	10.34	21080.548f	.293	11.11
20295.809f	.032	10.06	20690.693f	.418	10.24	21081.543f	.385	11.15
20313.744f	.344	11.15	20693.658f	.220	10.96	21126.513f	.165	10.96
20325.730f	.129	10.79	20695.689f	.443	9.95	21169.493f	.215	11.05
20336.675f	.228	11.05	20696.661f	.059	10.36	21309.858f	.043	10.27
20337.706f	.356	11.15	20708.671f	.320	11.15	21332.835f	.426	10.01
20343.667f	.442	10.06	20709.626f	.372	11.13	21374.710f	.275	11.09
20348.676f	.028	10.17	20719.558f	.362	11.11	21397.662f	.181	11.15
20350.619f	.164	11.11	20749.517f	.045	10.22	21425.624f	.126	10.85
20352.595f	.332	11.05	20756.503f	.252	11.15	21428.612f	.403	10.31
20353.652f	.034	10.52	20777.491f	.002	10.06	21438.562f	.411	10.17
20355.609f	.183	11.07	20938.892f	.078	10.68	21449.532f	.084	10.58
20372.550f	.404	10.74	20994.837f	.441	9.95	21453.498f	.436	10.01
20386.571f	.417	10.22	21007.831f	.330	11.04	21756.681f	.401	10.79
20392.587f	.106	10.68	21009.799f	.039	10.24	21757.668f	.032	10.24
20429.549f	.013	10.06	21010.764f	.100	10.68	21790.624f	.000	10.01
20441.551f	.266	10.01	21011.741f	.173	10.41	21804.620f	.440	10.01
20594.869f	.394	11.02	21017.643f	.201	11.07	22129.600f	.059	10.31
20607.769f	.189	11.05	21021.714f	.205	11.09	22138.551f	.424	10.06
20612.836f	.286	11.15	21022.675f	.262	11.07	22161.647f	.022	10.24
20654.735f	.159	11.07	21047.719f	.000	9.90	22175.559f	.377	11.07
20662.726f	.016	10.06	21051.663f	.329	11.05	22488.631f	.290	11.02
20667.712f	.031	10.24	21065.624f	.282	11.15	22516.680f	.322	11.09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5.5
5.0
5.5
5.0
5.5
8.0
8.5
7.0
7.5
K Pav
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1899-1908
1908-1918
1918-1926
YZ Sgr
p=9.5531
S Nor
p=9.75

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and	S Ara		J. D. and	S Ara		J. D. and	S Ara	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
22525.630f	0.234	11.07	23307.518f	0.354	11.05	24326.691z	0.063	10.79
22542.548f	.432	10.01	23533.861f	.300	11.15	24356.582z	.129	10.96
22543.555f	.084	10.68	23576.711f	.226	11.15	24371.635z	.270	11.07
22577.520f	.157	10.85	23647.560f	.123	10.85	24411.522z	.391	10.52
22584.512f	.371	11.09	23648.551f	.210	10.58	24433.512z	.238	11.09
23172.861f	.359	11.09	23673.530f	.336	11.11	24626.522z	.291	11.02
23191.710f	.229	11.07	23692.532f	.358	11.09	24648.701z	.327	11.09
23194.791f	.147	10.85	23902.865z	.110	10.85	24670.700z	.184	10.85
23197.776f	.420	10.31	23918.780z	.209	11.02	24704.697z	.289	11.00
23219.670f	.172	10.85	24273.870z	.114	10.79	24716.776z	.167	11.04
23222.681f	.020	10.29	24296.758z	.407	10.41	24798.505z	.104	10.79
23236.691f	.021	10.34	24318.702z	.209	11.09	25382.539z	.296	11.00
23237.677f	.103	10.68						

J. D. and	κ Pav		J. D. and	κ Pav		J. D. and	κ Pav	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
14863.64f	6.49	5.20	15189.67f	5.35	5.49	15560.71f	3.79	5.44
14871.63f	5.39	5.44	15221.68f	1.01	5.03	15561.63f	4.71	5.67
14871.68f	5.44	5.38	15267.53f	1.42	5.15	15590.66f	6.51	5.38
14874.64f	8.40	4.79	15274.58f	8.47	4.47	15602.65f	0.29	4.87
14925.52f	4.76	5.32	15481.81f	6.68	5.32	15607.61f	5.25	5.44
14927.57f	6.81	5.20	15519.62f	8.18	4.55	15633.57f	3.94	5.49
15116.88f	5.27	5.61	15533.65f	4.03	5.44	15646.54f	7.86	4.71
15148.68f	0.72	4.87	15541.79f	3.04	5.52	15659.52f	2.63	5.38

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	κ Pav		J. D. and Telescope	κ Pav		J. D. and Telescope	κ Pav	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
15842.88f	4.23	5.49	16287.65f	3.65	5.32	16706.60f	4.59	5.44
15868.82f	2.90	5.44	16302.66f	0.52	4.79	16713.68f	2.58	5.32
15872.89f	6.97	5.26	16310.73f	8.59	4.71	16726.60f	6.41	5.32
15887.68f	3.59	5.44	16311.59f	0.36	4.79	16745.54f	7.18	4.95
15898.68f	5.51	5.49	16338.65f	0.16	4.79	16760.56f	4.02	5.44
15906.79f	4.52	5.49	16345.66f	7.17	5.20	16915.89f	4.85	5.44
15911.77f	0.41	4.87	16358.62f	1.95	5.32	16932.88f	3.67	5.38
15927.72f	7.28	5.20	16379.55f	4.71	5.52	16937.88f	8.67	4.71
15931.54f	2.01	5.32	16398.56f	5.54	5.32	16957.80f	1.32	5.20
15934.69f	5.16	5.44	16582.86f	8.08	4.87	16960.76f	4.32	5.44
15940.55f	1.93	5.32	16593.75f	0.79	5.20	16968.75f	3.19	5.44
15941.69f	3.07	5.26	16594.81f	1.85	5.44	16975.77f	1.12	5.32
15945.71f	7.09	5.15	16604.74f	2.70	5.44	16981.83f	7.18	5.15
15973.59f	7.71	4.79	16605.84f	3.80	5.44	16999.77f	6.94	5.26
16008.58f	6.34	5.26	16607.80f	5.76	5.32	17000.78f	7.95	4.79
16045.53f	6.94	5.44	16625.73f	5.51	5.49	17002.71f	0.79	4.79
16183.87f	8.96	4.63	16634.80f	5.49	5.44	17006.76f	4.84	5.49
16221.86f	1.51	5.15	16641.72f	3.32	5.49	17032.82f	3.64	5.49
16229.86f	0.42	4.79	16653.61f	6.13	5.49	17038.53f	0.26	5.03
16254.78f	7.17	5.20	16662.73f	6.16	5.44	17039.56f	1.29	5.20
16269.73f	3.94	5.44	16667.61f	1.95	5.44	17069.62f	4.09	5.61
16278.72f	3.84	5.44	16680.53f	5.78	5.32	17094.59f	1.79	5.32
16282.77f	7.89	4.87	16685.62f	1.78	5.20	17097.58f	4.78	5.44
16285.67f	1.71	5.15	16697.57f	4.65	5.44	17125.54f	5.48	5.38

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	κ Pav		J. D. and Telescope	κ Pav		J. D. and Telescope	κ Pav	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
17297.84f	5.11	5.44	17760.69f	4.47	5.44	18191.54f	8.18	4.79
17335.76f	6.68	5.32	17772.74f	7.43	5.03	18361.89f	5.86	5.44
17341.78f	3.61	5.49	17792.63f	0.06	4.95	18362.88f	6.85	5.20
17352.83f	5.57	5.38	17803.61f	1.95	5.38	18420.82f	1.18	5.09
17376.80f	2.28	5.20	17835.54f	6.62	5.44	18422.82f	3.18	5.44
17377.75f	3.23	5.44	17836.53f	7.61	4.87	18434.78f	6.05	5.44
17384.68f	1.07	5.03	18026.88f	7.11	5.26	18438.75f	0.93	4.87
17390.69f	7.08	4.95	18033.89f	5.03	5.44	18444.77f	6.95	5.26
17401.72f	9.02	4.63	18041.86f	3.91	5.61	18451.70f	4.79	5.52
17402.72f	0.93	5.20	18070.79f	5.58	5.49	18456.80f	0.70	4.79
17430.65f	1.60	5.32	18081.77f	7.47	4.79	18466.77f	1.69	5.15
17431.61f	2.56	5.44	18082.86f	8.56	4.87	18467.76f	2.68	5.32
17436.61f	7.56	4.79	18102.78f	1.22	4.95	18478.79f	4.62	5.52
17464.56f	8.24	4.87	18109.69f	8.13	4.87	18479.75f	5.58	5.49
17489.53f	5.95	5.44	18118.62f	7.97	4.79	18481.63f	7.46	5.15
17499.52f	6.85	5.20	18129.58f	0.75	4.87	18494.74f	2.39	5.26
17505.51f	3.75	5.49	18132.71f	3.88	5.49	18498.69f	6.34	5.44
17690.81f	7.29	5.26	18145.57f	7.65	4.87	18502.58f	1.14	5.03
17704.72f	3.03	5.38	18150.66f	3.66	5.52	18508.67f	7.23	5.32
17718.73f	7.95	4.71	18154.65f	7.65	4.79	18528.63f	9.02	4.79
17730.70f	1.74	5.44	18159.52f	3.44	5.49	18533.60f	4.80	5.44
17735.70f	6.74	5.26	18172.60f	7.42	4.87	18538.51f	0.72	4.87
17738.79f	0.75	5.20	18187.57f	4.21	5.61	18539.58f	1.79	5.26
17758.77f	2.55	5.44	18190.55f	7.19	5.20	18540.62f	2.83	5.44

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	κ Pav		J. D. and Telescope	κ Pav		J. D. and Telescope	κ Pav	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
18561.52f	5.56	5.44	19222.74f	3.35	5.44	19515.87f	5.67	5.32
18602.51f	1.11	4.87	19224.69f	5.30	5.61	19516.86f	6.66	5.32
18767.85f	2.86	5.44	19231.66f	3.18	5.44	19532.76f	4.38	5.38
18778.84f	4.76	5.52	19234.63f	6.15	5.44	19548.80f	2.24	5.20
18791.81f	8.65	4.79	19235.57f	7.09	5.26	19550.75f	4.19	5.32
18804.85f	3.51	5.52	19239.64f	2.08	5.44	19560.72f	5.08	5.32
18806.78f	5.44	5.67	19239.73f	2.17	5.44	19565.75f	1.02	5.20
18828.68f	0.08	4.71	19250.65f	4.00	5.49	19567.71f	2.98	5.44
18832.67f	4.07	5.44	19251.63f	4.98	5.44	19569.78f	5.05	5.44
18852.62f	5.84	5.44	19252.51f	5.86	5.38	19575.69f	1.87	5.20
18856.73f	0.86	4.87	19254.59f	7.94	4.79	19575.82f	2.00	5.32
18860.65f	4.84	5.44	19254.63f	7.98	5.09	19589.86f	6.82	5.15
18896.61f	4.39	5.44	19267.61f	2.78	5.38	19599.69f	7.69	4.79
18917.58f	7.18	5.26	19290.54f	7.54	4.87	19601.73f	0.65	5.09
18938.53f	0.87	4.87	19294.60f	2.51	5.44	19603.74f	2.66	5.32
19136.87f	8.36	4.79	19300.63f	8.54	4.71	19617.71f	7.54	4.87
19177.81f	3.86	5.49	19301.50f	0.32	4.79	19634.60f	6.25	5.26
19180.89f	6.94	5.38	19305.60f	4.42	5.67	19634.65f	6.30	5.32
19196.77f	4.65	5.44	19311.57f	1.30	4.79	19634.70f	6.35	5.38
19203.76f	2.55	5.32	19312.52f	2.25	5.32	19648.57f	2.05	5.20
19205.77f	4.56	5.52	19323.52f	4.16	5.49	19652.68f	6.16	5.44
19213.71f	3.41	5.49	19329.55f	1.11	4.75	19653.51f	6.99	5.26
19213.76f	3.46	5.44	19509.83f	8.71	4.47	19658.61f	3.00	5.44
19220.75f	1.36	5.20	19510.85f	0.65	4.79	19663.58f	7.97	4.79

TABLE IV.—Photographic Observations of Cepheid Variable Stars.—*Cont.*

Section C

J. D. and	κ Pav		J. D. and	κ Pav		J. D. and	κ Pav	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
19693.52f	1.56	5.32	20287.73f	5.05	5.49	20423.59f	4.59	5.44
19693.55f	1.59	5.38	20287.77f	5.09	5.44	20429.55f	1.46	4.71
19891.86f	0.76	4.63	20295.81f	4.04	5.44	20594.87f	3.19	5.32
19902.84f	1.89	5.03	20308.80f	7.84	4.79	20607.77f	7.01	5.26
19917.79f	7.71	4.71	20313.74f	3.79	5.44	20612.84f	2.99	5.26
19925.78f	6.62	5.09	20314.73f	4.83	5.44	20654.74f	8.54	4.71
19929.66f	1.41	5.26	20334.75f	6.63	5.38	20662.73f	7.44	4.87
19930.65f	2.40	5.20	20336.68f	8.56	4.47	20664.86f	0.48	5.15
19942.85f	5.51	5.44	20337.71f	0.50	4.79	20667.71f	3.34	5.38
19945.75f	8.41	4.47	20343.67f	6.46	4.87	20669.69f	5.31	5.49
19952.64f	6.21	5.32	20350.62f	4.32	5.67	20681.74f	8.27	4.71
19954.66f	8.23	5.03	20352.60f	6.30	5.32	20690.64f	8.08	4.95
19971.68f	7.08	5.32	20353.65f	7.35	4.63	20690.69f	8.13	4.79
19971.80f	7.20	5.34	20353.69f	7.39	4.87	20691.67f	0.03	4.95
19974.63f	0.94	4.63	20355.61f	0.22	4.39	20693.66f	2.02	5.03
19974.77f	1.08	4.71	20358.67f	3.28	5.38	20695.69f	4.05	5.67
19985.61f	2.84	5.32	20362.55f	7.16	5.26	20695.74f	4.10	5.49
19987.53f	4.75	5.32	20362.67f	7.20	5.26	20696.66f	5.02	5.44
20012.53f	2.49	5.26	20372.55f	8.07	4.71	20698.57f	6.93	5.38
20013.60f	3.56	5.44	20386.57f	3.92	5.44	20708.67f	7.94	4.71
20043.62f	6.31	5.44	20386.64f	3.99	5.44	20709.63f	8.90	4.79
20047.62f	1.22	4.39	20392.59f	0.85	4.71	20710.58f	0.76	5.20
20063.52f	8.04	4.55	20392.68f	0.94	4.71	20711.71f	1.89	5.38
20282.80f	0.12	4.47	20423.54f	4.54	5.32	20719.56f	0.65	4.89

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and	κ Pav		J. D. and	κ Pav		J. D. and	κ Pav	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
20739.68f	2.60	5.44	21022.68f	3.87	5.32	21373.72f	0.48	4.79
20749.52f	3.35	5.44	21025.82f	7.01	5.38	21374.71f	1.47	4.87
20751.52f	5.35	5.49	21038.77f	1.78	5.38	21396.81f	5.39	5.44
20756.50f	1.24	4.87	21046.68f	0.60	4.87	21397.66f	6.24	5.44
20756.33f	1.27	5.20	21047.72f	1.64	4.95	21398.78f	7.36	5.38
20757.56f	2.30	5.32	21050.68f	4.60	5.61	21421.66f	2.98	5.44
20775.55f	2.11	5.38	21051.66f	5.58	5.49	21425.62f	6.94	5.09
20777.49f	4.05	5.44	21064.63f	0.38	4.79	21428.61f	0.84	4.79
20778.55f	5.11	5.49	21065.62f	1.37	5.03	21429.62f	1.85	5.26
20783.50f	0.98	5.20	21078.54f	5.20	5.61	21438.56f	1.70	4.95
20938.89f	1.87	5.32	21078.68f	5.34	5.44	21438.62f	1.76	5.20
20938.91f	1.89	5.20	21080.55f	7.21	5.20	21440.58f	3.72	5.38
20991.81f	0.26	4.95	21081.54f	8.20	4.87	21447.68f	1.73	5.38
20994.84f	3.29	5.32	21092.63f	1.11	5.15	21449.53f	3.58	5.61
21007.83f	7.19	4.95	21093.67f	2.15	5.32	21453.50f	7.55	5.15
21007.86f	7.22	5.32	21126.51f	7.73	4.71	21453.64f	7.69	5.32
21009.80f	0.08	4.87	21135.53f	7.66	4.95	21455.66f	0.62	4.87
21010.76f	1.04	4.79	21138.56f	1.60	5.32	21756.68f	1.74	5.03
21011.74f	2.02	5.20	21169.49f	5.27	5.61	21757.67f	2.73	5.20
21011.84f	2.12	5.44	21309.86f	0.23	4.79	21789.64f	7.44	5.32
21013.76f	4.04	5.61	21331.87f	4.07	5.44	21790.62f	8.42	4.87
21017.64f	7.92	4.71	21332.84f	5.04	5.44	21804.62f	4.24	5.32
21017.81f	8.09	5.15	21333.89f	6.09	5.38	21805.56f	5.49	5.67
21021.71f	2.90	5.61	21362.78f	7.71	5.26	21808.68f	8.30	5.26

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	κ Pav Phase	Mag.	J. D. and Telescope	κ Pav Phase	Mag.	J. D. and Telescope	κ Pav Phase	Mag.
21814.67f	5.20	5.44	22584.51f	2.56	4.87	23307.52f	7.62	5.44
21824.63f	6.07	5.20	22850.65f	5.15	5.44	23320.54f	2.46	4.79
21833.62f	5.98	5.32	22871.65f	7.97	5.20	23338.53f	2.28	4.71
21834.62f	6.98	5.44	22936.53f	0.15	4.79	23533.86f	6.76	5.61
21874.51f	1.43	4.63	23176.86f	0.19	5.26	23535.74f	8.64	5.15
22082.86f	9.84	4.23	23179.76f	7.09	5.44	23533.86f	6.76	5.61
22129.60f	2.05	4.63	23191.71f	0.87	4.79	23535.74f	8.64	5.38
22138.55f	1.91	4.71	23194.79f	3.95	5.26	23566.84f	3.39	4.87
22161.65f	6.84	5.49	23197.78f	6.94	5.52	23573.82f	1.28	4.71
22164.58f	0.68	4.79	23206.74f	6.81	5.49	23576.71f	4.17	5.26
22175.56f	2.57	4.79	23209.72f	0.70	4.71	23619.65f	1.67	4.71
22190.61f	8.53	5.03	23219.67f	1.56	4.87	23647.56f	2.32	4.87
22193.53f	2.37	4.87	23221.70f	3.59	5.44	23648.55f	3.31	4.95
22196.56f	5.40	5.49	23222.68f	4.57	5.38	23673.53f	1.02	4.79
22229.53f	2.01	4.79	23234.61f	7.41	5.44	23692.53f	1.85	4.79
22256.54f	1.76	5.15	23236.69f	0.41	5.03	23902.87z	3.16	4.79
22488.63f	6.65	5.20	23237.68f	1.40	4.79	23918.78z	0.90	4.95
22516.64f	7.40	5.32	23247.59f	2.22	4.87	24273.87z	1.55	4.87
22516.68f	7.44	5.32	23250.76f	5.39	5.44	24296.76z	6.27	5.44
22525.63f	7.30	5.20	23251.68f	6.31	5.73	24299.72z	0.14	5.20
22542.55f	6.04	5.44	23265.65f	2.10	4.87	24318.70z	0.94	5.15
22543.56f	7.04	5.32	23269.61f	6.06	5.67	24319.76z	2.00	4.79
22577.52f	4.66	5.61	23278.58f	5.94	5.44	24326.69z	8.93	5.44
22578.52f	5.66	5.61	23282.58f	0.86	4.79	24328.69z	1.85	4.87

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	κ Pav		J. D. and Telescope	κ Pav		J. D. and Telescope	κ Pav	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
24352.62z	7.60	5.61	24626.52z	8.86	5.44	24716.78z	8.23	5.44
24356.58z	2.47	5.09	24647.71z	2.79	4.79	24728.57z	1.85	4.87
24371.57z	8.37	5.44	24648.70z	3.78	5.20	24732.64z	5.92	5.44
24371.64z	8.44	5.49	24670.70z	7.60	5.61	24755.58z	1.60	5.03
24411.52z	2.88	4.87	24704.70z	5.25	5.32	24788.54z	7.30	5.67
24433.51z	6.70	5.73	24705.62z	6.17	5.38			

J. D. and Telescope	BB Sgr		J. D. and Telescope	BB Sgr		J. D. and Telescope	BB Sgr	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
14874.69f	6.02	7.53	15533.69f	1.34	7.73	15885.83f	1.73	8.14
14876.60f	1.29	7.73	15542.83f	3.84	8.58	15890.82e	0.08	7.73
14890.60f	2.02	8.41	15557.62f	5.36	7.94	15897.70f	0.32	7.47
14904.57f	2.71	8.55	15558.68f	6.42	7.53	15903.83f	6.45	7.47
14919.58f	4.45	8.64	15561.67f	2.77	8.51	15914.69f	4.04	8.55
14939.60f	4.56	8.51	15575.67f	3.50	8.68	15925.75f	1.83	8.21
14953.53f	5.21	8.00	15602.56f	3.84	8.68	15930.69e	0.13	7.53
15148.72f	1.30	7.94	15611.63e	6.27	7.67	15933.68f	3.12	8.41
15151.83e	4.41	8.48	15627.56e	2.29	8.48	15934.65f	4.09	8.55
15233.72e	0.02	7.47	15632.57f	0.66	7.47	15940.64f	3.44	8.51
15248.65e	1.68	8.34	15634.57f	2.66	8.34	15944.67e	0.84	7.40
15264.57f	4.33	8.68	15635.58e	3.67	8.51	15962.60e	5.49	8.07
15308.53f	1.83	8.21	15653.51e	1.69	8.27	15962.63e	5.52	7.94
15518.83e	6.39	7.33	15665.49e	0.40	7.67	15971.56f	1.18	8.21
15532.70f	0.35	7.47	15855.88f	4.96	8.27	15974.61e	4.23	8.55

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	BB Sgr		J. D. and Telescope	BB Sgr		J. D. and Telescope	BB Sgr	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
15988.55e	4.89	8.34	16319.54f	4.04	8.64	16679.70e	2.45	8.21
15993.54f	3.25	8.34	16340.65f	5.24	8.48	16683.52f	3.00	8.34
16006.60f	3.03	8.34	16341.59e	6.18	7.80	16683.62f	3.10	8.41
16007.60e	4.03	8.64	16344.58e	2.54	8.41	16697.67f	3.88	8.48
16010.57f	0.37	7.67	16348.60e	6.56	7.73	16711.58f	4.51	8.48
16016.59e	6.39	7.94	16359.61f	4.29	8.58	16719.54e	5.84	7.80
16023.57f	0.09	7.47	16361.62f	6.30	7.40	16724.53e	4.19	8.68
16027.55f	4.07	8.58	16372.54e	3.95	8.61	16724.59f	4.25	8.58
16033.52f	3.41	8.48	16376.62f	1.39	8.14	16726.55f	6.21	7.60
16043.50e	0.11	7.40	16407.53f	5.76	7.67	16728.54e	1.56	8.34
16055.47e	5.45	8.21	16583.83f	2.86	8.51	16753.53f	0.01	7.67
16226.81f	4.23	8.64	16593.79f	6.19	7.53	16755.52f	2.00	8.48
16230.81f	1.59	8.07	16606.80f	5.92	7.67	16760.53e	0.37	7.33
16241.73f	5.88	7.60	16608.89f	1.38	7.94	16766.51f	6.35	7.67
16243.84e	1.35	8.41	16614.78f	0.63	7.80	16922.89f	3.45	8.55
16253.71f	4.58	8.27	16617.83e	3.68	8.61	16943.84f	4.49	8.51
16254.82f	5.69	7.73	16635.72f	1.66	8.27	16958.82f	6.19	7.87
16265.79e	3.39	8.48	16639.71f	5.65	8.07	16968.80f	2.90	8.34
16268.87f	6.47	7.80	16643.78e	3.08	8.41	16976.79f	4.25	8.71
16284.84f	2.53	8.58	16649.71e	2.38	8.31	16979.77f	0.60	7.80
16292.77f	3.82	8.55	16650.72f	3.39	8.55	17000.82f	1.74	8.34
16297.69f	2.11	8.27	16663.80f	3.19	8.41	17004.65f	5.57	8.14
16308.64f	6.42	7.73	16669.79f	2.54	8.48	17006.77e	1.05	7.47
16311.63f	2.77	8.41	16670.74e	3.49	8.55	17009.77f	4.05	8.61

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	BB Sgr		J. D. and Telescope	BB Sgr		J. D. and Telescope	BB Sgr	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
17010.69f	4.97	8.61	17376.67f	5.92	7.60	17758.72f	3.04	8.55
17018.67f	6.31	7.53	17380.73f	3.35	8.68	17769.71e	0.76	7.33
17019.77f	0.77	7.94	17384.72f	0.70	7.67	17774.72f	5.77	8.07
17032.77f	0.50	7.60	17394.61f	3.95	8.61	17787.64f	5.41	8.27
17034.67e	2.40	8.34	17394.74f	4.08	8.68	17798.60e	3.10	8.58
17038.62f	6.35	7.60	17403.72f	6.43	7.53	17801.61e	6.11	7.40
17039.61f	0.70	7.73	17417.75e	0.55	7.33	17813.50f	4.73	8.41
17048.67e	3.13	8.27	17436.66f	6.18	7.80	17813.55f	4.78	8.55
17053.72f	1.54	8.27	17441.60e	4.49	8.55	17814.59e	5.82	7.67
17066.72f	1.27	8.34	17445.60f	1.85	8.34	17816.63f	1.22	8.51
17076.61f	4.52	8.64	17445.60e	1.85	8.34	17820.55f	5.14	8.51
17076.67f	4.58	8.68	17447.57f	3.82	8.51	17836.57f	1.25	8.27
17077.65f	5.56	8.07	17450.55f	0.16	7.87	17849.55e	0.96	7.67
17084.55e	5.82	7.67	17462.54e	5.52	8.21	17858.53e	3.30	8.48
17105.61f	0.34	7.73	17465.56f	1.90	8.21	17850.54e	1.95	7.67
17107.62f	2.35	8.34	17485.59f	2.02	8.41	18027.89f	0.10	7.80
17110.56e	5.29	8.21	17496.49e	6.28	7.33	18042.86f	1.80	8.21
17132.49e	0.67	8.07	17683.87f	1.20	8.27	18042.90f	1.84	8.48
17135.56f	3.74	8.74	17703.90f	1.31	8.14	18063.83e	2.86	8.34
17325.84f	1.55	8.27	17709.84e	0.62	7.80	18064.83e	3.86	8.68
17335.80f	4.88	8.55	17727.75f	5.25	8.34	18082.75f	1.87	8.41
17360.72f	3.25	8.34	17734.84f	5.71	8.07	18097.79e	3.63	8.48
17366.75e	2.64	8.48	17738.84f	3.07	8.55	18097.85f	3.69	8.55
17373.79e	3.04	8.34	17746.73e	4.32	8.55	18111.78f	4.35	8.74

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	BB Sgr Phase	BB Sgr Mag.	J. D. and Telescope	BB Sgr Phase	BB Sgr Mag.	J. D. and Telescope	BB Sgr Phase	BB Sgr Mag.
18122.73e	2.03	8.21	18467.80f	1.98	8.55	18594.52f	2.60	8.48
18129.76e	2.42	8.41	18472.69f	0.24	7.47	18806.87f	2.58	8.51
18130.68f	3.34	8.61	18477.80f	5.35	8.21	18820.82f	3.25	8.48
18132.66f	5.32	8.34	18495.74e	3.38	8.48	18821.79f	4.22	8.74
18156.61f	2.72	8.34	18499.71f	0.71	7.94	18821.84f	4.27	8.71
18158.53f	4.64	8.64	18500.72f	1.72	8.14	18824.85f	0.65	8.00
18158.58f	4.69	8.64	18501.59f	2.59	8.48	18825.77f	1.57	8.07
18171.53f	4.37	8.55	18503.70f	4.70	8.64	18825.79e	1.59	8.00
18174.59e	0.79	7.94	18505.66f	0.02	7.67	18827.79e	3.59	8.55
18181.57e	1.14	8.00	18506.68f	1.04	8.07	18831.76f	0.92	8.07
18181.66f	1.23	8.41	18512.61f	0.34	7.60	18832.72f	1.88	8.34
18183.53f	3.10	8.41	18516.60f	4.33	8.71	18834.83f	3.99	8.68
18183.58e	3.15	8.21	18526.63e	1.08	7.87	18848.79f	4.68	8.55
18199.56f	5.85	7.87	18531.61f	6.06	7.53	18849.76f	5.65	8.21
18209.53f	2.55	8.48	18533.55f	1.37	8.21	18855.75f	5.00	8.55
18214.51e	0.89	7.60	18534.63f	2.45	8.34	18857.70e	0.31	7.47
18221.53f	1.28	8.34	18539.64f	0.82	8.21	18859.70f	2.31	8.34
18221.55e	1.30	8.27	18541.50f	2.68	8.41	18859.72e	2.33	8.34
18427.84f	1.84	8.48	18561.56f	2.83	8.68	18864.76f	0.74	8.07
18438.84f	6.21	8.00	18565.53f	0.16	7.73	18870.70f	0.04	7.73
18441.75f	2.48	8.34	18568.52e	3.15	8.41	18884.63f	0.70	7.80
18451.82e	5.91	7.80	18569.55f	4.18	8.68	18889.69f	5.76	8.00
18453.80f	1.26	8.14	18571.52f	6.15	7.94	18911.62f	1.14	7.80
18454.83f	2.19	8.21	18574.53f	2.52	8.21	18918.57f	1.45	7.94

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	BB Sgr		J. D. and Telescope	BB Sgr		J. D. and Telescope	BB Sgr	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
18919.54f	2.42	8.27	19265.60e	3.37	8.34	19601.68f	0.97	7.80
18943.54e	6.51	7.60	19276.56f	1.05	7.94	19603.65f	2.94	8.34
18948.50e	4.83	8.51	19290.58f	1.80	8.41	19603.70f	2.99	8.48
19153.83f	4.42	8.61	19292.54e	3.76	8.48	19604.55f	3.84	8.51
19195.80e	6.57	7.67	19292.56f	3.78	8.64	19606.64f	5.93	7.60
19204.74f	2.24	8.21	19300.50f	5.08	8.34	19616.67f	2.69	8.34
19206.73f	4.23	8.61	19300.53e	5.11	8.21	19631.62f	4.36	8.51
19213.67f	4.53	8.68	19301.54f	6.12	8.00	19632.58f	5.32	8.14
19215.74f	6.60	7.73	19310.52f	1.83	8.34	19645.63f	5.10	8.21
19218.75e	2.98	8.34	19311.53f	2.84	8.41	19650.65f	3.48	8.34
19224.65f	2.24	8.41	19327.51f	5.55	7.94	19652.56f	5.39	8.00
19225.61f	3.20	8.41	19511.82f	4.03	8.64	19655.56f	1.76	8.00
19232.75f	3.70	8.51	19513.85f	6.06	7.60	19656.56f	2.76	8.41
19233.66f	4.61	8.51	19518.82f	4.39	8.68	19657.56f	3.76	8.48
19234.72f	5.67	8.07	19532.72f	5.02	8.34	19658.53e	4.73	8.55
19236.66f	0.98	8.21	19542.81f	1.83	8.00	19660.54f	0.10	7.47
19237.67e	1.99	8.00	19545.81f	4.83	8.48	19676.51f	2.80	8.27
19238.70f	3.02	8.61	19561.72f	0.83	7.67	19677.52f	3.81	8.51
19240.67e	4.99	8.27	19562.69f	1.80	8.00	19690.48e	3.49	8.48
19241.61f	5.93	7.87	19566.70f	5.81	7.73	19711.53f	4.63	8.48
19251.67f	2.71	8.48	19571.80f	4.28	8.55	19889.88f	3.79	8.55
19253.60f	4.64	8.58	19572.70f	5.18	8.21	19896.80f	4.07	8.51
19264.60f	2.37	8.34	19588.72f	1.29	8.00	19897.80f	5.07	8.51
19264.64f	2.41	8.48	19601.64f	0.93	7.73	19898.87f	6.14	7.53

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and	BB Sgr		J. D. and	BB Sgr		J. D. and	BB Sgr	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
19911.90f	5.90	7.94	19973.62f	1.25	7.73	20300.77e	3.20	8.27
19912.80f	0.16	7.67	19975.70f	3.33	8.55	20306.74f	2.53	8.14
19916.84e	4.20	8.55	19977.67f	5.30	8.07	20306.76e	2.55	8.21
19921.80e	2.53	8.27	19985.52f	6.51	7.53	20307.56f	3.35	8.34
19921.84f	2.57	8.34	19985.56f	6.55	7.47	20328.60f	4.48	8.58
19922.82f	3.55	8.41	19988.52f	2.88	8.51	20328.70f	4.58	8.48
19923.84f	4.57	8.48	19989.52f	3.88	8.55	20329.69f	5.57	8.07
19929.78e	3.87	8.55	20000.59e	1.67	8.07	20330.67f	6.55	7.47
19931.66f	5.75	7.53	20001.62e	2.70	8.27	20334.69e	3.93	8.51
19933.78e	1.23	7.73	20006.55e	1.00	7.80	20337.66f	0.27	7.47
19933.82f	1.27	8.00	20012.57f	0.38	7.47	20338.58f	1.19	7.87
19942.76f	3.58	8.48	20013.56f	1.37	8.00	20341.69f	4.30	8.51
19942.81f	3.63	8.48	20015.56f	3.37	8.41	20352.70f	2.03	8.27
19946.74e	0.92	7.94	20027.56f	2.10	8.21	20354.58f	3.91	8.58
19947.72f	1.90	8.00	20031.57f	6.11	7.60	20357.64f	0.34	7.40
19947.74e	1.92	8.00	20043.52f	4.78	8.55	20361.62f	4.32	8.55
19949.69f	3.87	8.64	20044.56f	5.82	7.60	20363.54f	6.24	7.60
19950.71f	4.89	8.48	20044.61f	5.87	7.60	20366.58f	2.64	8.21
19951.72f	5.90	7.67	20064.48e	5.83	7.47	20367.59f	3.65	8.61
19955.70e	3.24	8.41	20069.52f	4.24	8.58	20372.62f	2.04	8.27
19959.58f	0.49	7.73	20276.81e	5.79	7.73	20384.53f	0.68	7.73
19961.60f	2.51	8.21	20280.81e	3.15	8.34	20387.59f	3.74	8.61
19972.75f	0.38	7.47	20296.77e	5.84	7.40	20391.58f	1.09	8.07
19973.51f	1.14	7.80	20297.67f	0.10	7.53	20394.58f	4.09	8.55

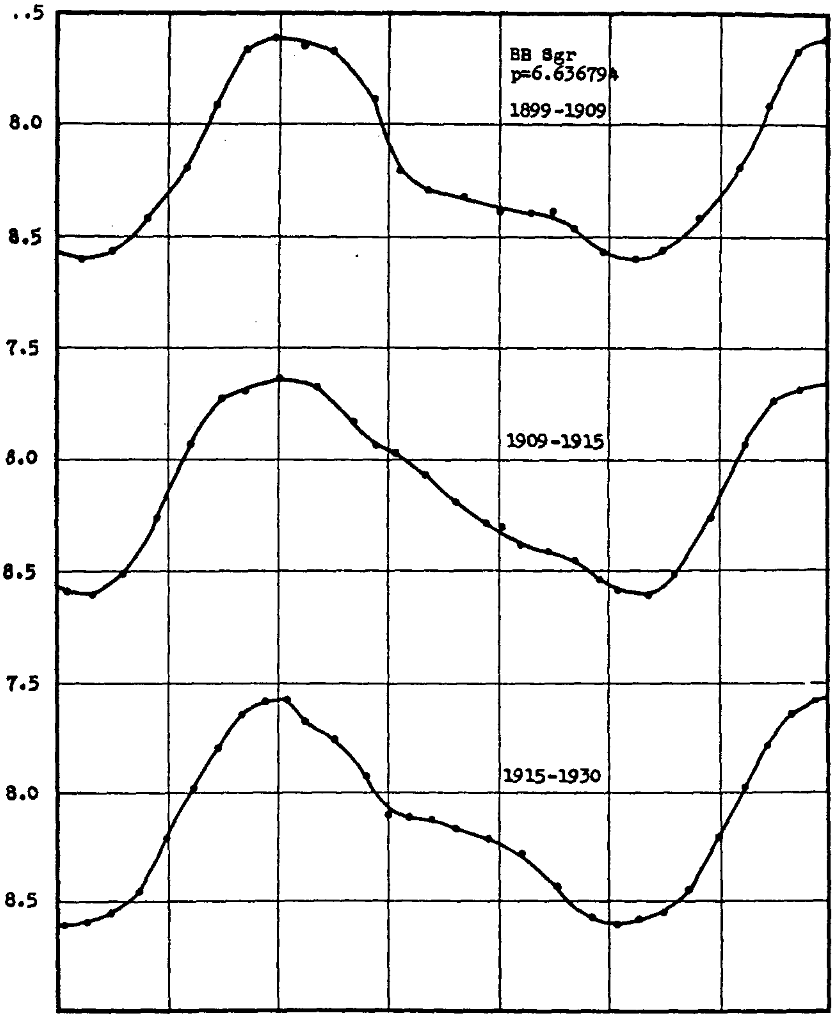
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TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	BB Sgr		J. D. and Telescope	BB Sgr		J. D. and Telescope	BB Sgr	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
20398.55f	1.43	7.94	20719.60f	3.91	8.55	21037.68e	3.42	8.21
20440.55f	3.61	8.64	20719.64f	3.95	8.51	21038.67f	4.41	8.55
20444.55f	0.97	7.80	20721.65f	5.96	7.53	21038.74e	4.48	8.55
20580.87e	4.55	8.48	20724.64f	2.31	8.21	21039.70f	5.44	7.80
20626.82f	4.05	8.51	20747.52f	5.28	7.94	21047.76f	0.23	7.47
20628.79e	6.02	7.40	20747.57f	5.33	7.94	21048.68f	1.15	7.73
20651.80f	2.48	8.41	20751.57f	2.70	8.07	21062.63f	1.83	8.00
20651.88f	2.56	8.34	20752.49f	3.62	8.55	21064.61e	3.81	8.48
20652.78f	3.46	8.55	20766.52f	4.37	8.74	21064.67f	3.87	8.58
20655.81f	6.49	7.73	20769.48f	0.70	7.67	21066.63f	5.83	7.73
20661.76f	5.80	7.94	20776.52f	1.10	8.21	21068.68f	1.24	8.21
20667.80f	5.20	8.41	20778.51f	3.09	8.27	21072.62f	5.18	7.87
20669.79f	0.56	7.60	21006.79f	5.72	7.80	21077.64f	3.56	8.51
20681.71f	5.84	8.07	21007.78f	0.01	7.73	21079.58f	5.50	8.21
20682.76f	0.25	7.60	21008.81f	1.10	7.67	21079.63f	5.55	7.80
20688.65e	6.14	7.40	21009.83f	2.12	8.21	21080.60f	6.52	7.26
20688.71f	6.20	7.87	21011.76f	4.05	8.68	21092.59f	5.24	8.34
20691.62f	2.48	8.21	21012.74f	5.03	8.51	21095.61e	1.62	8.14
20691.72f	2.58	8.41	21018.79f	4.44	8.64	21099.55f	5.56	7.73
20693.79f	4.65	8.51	21022.76f	1.78	7.94	21099.59f	5.60	8.00
20695.66f	6.52	7.53	21023.74f	2.76	8.21	21103.55f	2.93	8.07
20698.71f	2.93	8.34	21024.75f	3.77	8.61	21104.54f	3.92	8.58
20708.63f	6.21	7.94	21026.75f	5.77	7.94	21106.60e	5.98	7.87
20709.67f	0.62	7.67	21035.72f	1.46	7.87	21120.58e	0.05	7.53

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and Telescope	BB Sgr		J. D. and Telescope	BB Sgr		J. D. and Telescope	BB Sgr	
	Phase	Mag.		Phase	Mag.		Phase	Mag.
21121.52e	0.99	8.14	21437.60f	5.14	8.51	21803.62e	6.13	7.67
21135.52f	1.71	8.34	21447.64f	1.90	8.21	21804.62e	0.50	8.00
21137.53f	3.72	8.55	21450.60f	4.86	8.51	21805.62f	1.50	7.94
21147.49e	0.41	7.67	21451.58f	5.84	7.67	21806.66f	2.54	8.14
21154.52f	0.80	7.80	21453.54f	1.17	8.21	21817.57f	6.81	7.53
21155.49f	1.77	7.94	21453.59f	1.22	8.00	21817.60f	0.21	7.53
21156.51f	2.79	8.14	21455.56f	3.19	8.21	21818.58f	1.19	8.00
21157.51f	3.79	8.61	21455.60f	3.23	8.61	21819.58f	2.19	8.07
21160.50f	0.15	7.80	21460.55f	1.54	8.07	21819.59f	2.20	8.00
21161.50f	1.15	8.21	21460.60e	1.59	8.21	21821.62e	4.23	8.41
21343.82e	4.27	8.55	21462.52f	3.51	8.55	21835.56f	4.89	8.55
21364.83f	5.37	8.14	21476.58e	4.30	8.55	21836.54f	5.87	7.60
21374.79e	2.06	8.27	21483.53e	4.61	8.51	21844.56f	0.62	7.53
21393.75f	1.11	8.14	21515.48e	3.38	8.48	21847.54f	3.60	8.48
21394.76f	2.12	8.34	21515.49e	3.39	8.48	22029.90e	0.13	7.80
21398.67f	6.03	7.80	21523.53f	4.79	8.51	22073.83e	4.23	8.64
21398.70f	6.06	7.80	21535.46e	3.44	8.55	22083.86f	0.99	8.14
21399.70f	0.42	7.94	21675.90e	4.51	8.55	22135.67f	6.34	7.47
21400.72e	1.44	8.14	21757.67f	6.64	7.73	22148.66e	6.06	7.40
21402.69f	3.41	8.68	21758.72f	1.05	7.94	22165.62e	3.11	8.48
21424.63f	5.44	8.27	21758.76f	1.09	7.94	22166.51f	4.00	8.51
21425.67f	6.48	7.40	21778.67e	1.09	8.14	22173.65f	4.50	8.48
21427.62f	1.79	8.07	21788.68f	4.47	8.68	22173.65e	4.50	8.34
21428.66f	2.83	8.21	21790.67f	6.46	7.53	22191,59e	2.53	8.27

TABLE IV.—PHOTOGRAPHIC OBSERVATIONS OF CEPHEID VARIABLE STARS.—*Cont.*

SECTION C

J. D. and	BB Sgr		J. D. and	BB Sgr		J. D. and	BB Sgr	
Telescope	Phase	Mag.	Telescope	Phase	Mag.	Telescope	Phase	Mag.
22194.56f	5.50	7.87	22897.61e	5.05	8.48	23277.57f	0.08	7.60
22195.57f	6.51	7.67	22907.65e	1.82	8.14	23279.57f	2.08	8.07
22215.52e	6.55	7.33	22936.59f	4.21	8.51	23282.59e	5.10	8.14
22225.53f	3.29	8.51	22940.53e	1.51	8.34	23305.61f	1.57	8.14
22228.54f	6.30	7.87	22952.52e	6.87	7.40	23311.52f	0.84	7.80
22233.52e	4.64	8.55	22977.54e	5.34	8.34	23314.59f	3.91	8.74
22253.52f	4.73	8.55	22985.48e	0.01	7.26	23338.58f	1.36	8.07
22433.86e	5.88	8.07	23181.82f	3.88	8.71	23346.52f	2.66	8.27
22461.79e	0.62	7.67	23181.87f	3.93	8.64	23535.78f	6.09	7.47
22542.64f	1.83	8.21	23194.75f	3.54	8.55	23561.73f	5.49	7.87
22549.67f	2.23	8.41	23198.82f	0.97	7.53	23576.70f	0.63	8.00
22551.65f	4.21	8.61	23205.65f	1.16	8.27	23662.53f	0.10	7.40
22552.55f	5.11	8.34	23205.80f	1.31	8.21	23664.56f	2.13	8.41
22584.52e	3.89	8.61	23206.69f	2.20	8.07	23702.53f	0.28	7.47
22584.55f	3.92	8.55	23209.72f	5.23	8.21	23986.64e	5.65	7.80
22607.56f	0.38	7.80	23219.71f	1.95	8.34	24422.55e	3.53	8.55
22620.50e	0.05	7.53	23222.72f	4.96	8.41	24656.72e	5.41	8.21
22767.89e	1.33	8.34	23225.75f	1.35	8.27	24659.80e	1.85	7.94
22821.80e	2.25	7.87	23235.68f	4.65	8.55	25765.78e	6.13	7.67
22840.77e	1.31	7.94	23248.59f	4.28	8.71	25773.73e	0.80	7.67
22843.78e	4.32	8.58	23248.68f	4.37	8.48	25795.69e	2.85	8.07
22850.78f	4.68	8.58	23253.61f	2.67	8.27	25826.65e	0.63	7.80

TABLE V

NORMAL POINTS FOR TWENTY-FOUR CEPHEID VARIABLES

Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
1. V Centauri							
0.030	7.868	0.239	7.960	0.470	7.018	0.745	7.552
0.083	7.892	0.283	7.936	0.522	7.007	0.792	7.676
0.126	7.903	0.326	7.820	0.586	7.074	0.843	7.746
0.160	7.924	0.368	7.633	0.644	7.266	0.896	7.750
0.197	7.933	0.416	7.292	0.698	7.448	0.964	7.792
2. R Trianguli Australis							
0.029	8.005	0.279	7.910	0.538	7.094	0.736	7.730
0.075	8.022	0.337	7.766	0.561	7.178	0.799	7.774
0.116	8.034	0.387	7.506	0.582	7.236	0.864	7.839
0.157	8.018	0.411	7.285	0.632	7.316	0.929	7.974
0.213	7.979	0.456	7.145	0.682	7.510	0.979	8.022
3. U Normae							
0.104	11.243	0.351	10.760	0.573	10.254	0.799	10.954
0.127	11.246	0.406	10.489	0.616	10.431	0.842	11.133
0.190	11.205	0.445	10.125	0.665	10.664	0.896	11.202
0.239	11.074	0.492	9.953	0.709	10.774	0.962	11.212
0.287	10.888	0.539	10.066	0.755	10.804		
4. S Trianguli Australis							
0.024	7.440	0.265	7.730	0.517	6.512	0.750	7.183
0.070	7.614	0.316	7.469	0.555	6.599	0.824	7.260
0.118	7.789	0.370	7.176	0.598	6.740	0.888	7.264
0.167	7.816	0.423	6.904	0.641	6.796	0.932	7.292
0.222	7.819	0.478	6.606	0.689	6.927	0.978	7.364
5. U Trianguli Australis							
0.013	8.786	0.349	8.688	0.608	8.146	0.823	8.659
0.084	8.808	0.384	8.532	0.647	8.192	0.873	8.714
0.146	8.814	0.433	8.272	0.666	8.308	0.938	8.746
0.200	8.838	0.479	8.006	0.696	8.400		
0.254	8.829	0.530	8.020	0.738	8.460		
0.310	8.775	0.561	8.123	0.779	8.562		

TABLE V.—NORMAL POINTS FOR TWENTY-FOUR CEPHEID VARIABLES.—*Cont.*

Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
6. S Normae							
0.006	7.843	0.292	7.448	0.581	7.308	0.867	7.793
0.065	7.833	0.355	7.387	0.626	7.337	0.906	7.796
0.119	7.776	0.415	7.290	0.688	7.380	0.952	7.826
0.177	7.675	0.471	7.198	0.722	7.544		
0.234	7.619	0.532	7.202	0.756	7.706		
0.265	7.542	0.549	7.218	0.817	7.767		
7. RW Trianguli Australis							
0.010	11.528	0.318	11.659	0.542	10.927	0.773	11.352
0.055	11.568	0.361	11.580	0.572	10.991	0.810	11.395
0.105	11.606	0.419	11.404	0.606	11.035	0.850	11.375
0.149	11.651	0.462	11.173	0.650	11.122	0.888	11.402
0.208	11.680	0.483	10.929	0.696	11.247	0.921	11.472
0.271	11.685	0.512	10.836	0.736	11.309	0.960	11.501
8. RV Scorpii.							
0.022	8.046	0.330	7.779	0.617	7.329	0.879	7.789
0.072	8.084	0.379	7.528	0.655	7.479	0.935	7.930
0.124	8.104	0.428	7.316	0.687	7.518	0.980	8.016
0.171	8.122	0.476	7.121	0.724	7.560		
0.218	8.111	0.532	7.115	0.764	7.615		
0.274	8.002	0.580	7.226	0.818	7.688		
9. X Sagittarii.							
1.							
0.012	5.964	0.366	5.276	0.583	5.160	0.768	5.500
0.086	5.937	0.435	4.996	0.645	5.224	0.805	5.634
0.218	5.539	0.507	4.865	0.696	5.312	0.866	5.774
0.325	5.334	0.549	4.965	0.734	5.416	0.938	5.885
2.							
0.056	5.848	0.305	5.839	0.512	4.850	0.755	5.617
0.126	5.928	0.366	5.672	0.571	5.032	0.826	5.697
0.194	5.966	0.415	5.369	0.623	5.264	0.898	5.856
0.249	5.899	0.457	5.021	0.685	5.485	0.978	5.877
3.							
0.019	5.828	0.219	5.956	0.446	4.959	0.778	5.479
0.072	5.869	0.280	5.924	0.522	4.943	0.851	5.533
0.110	5.922	0.338	5.682	0.602	5.180	0.892	5.651
0.155	5.961	0.394	5.312	0.681	5.336	0.949	5.779

TABLE V.—NORMAL POINTS FOR TWENTY-FOUR CEPHEID VARIABLES.—*Cont.*

4.

Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag
0.040	5.782	0.318	5.622	0.588	4.908	0.803	5.384
0.108	5.805	0.401	5.380	0.628	5.075	0.856	5.504
0.182	5.807	0.489	4.980	0.688	5.176	0.920	5.664
0.249	5.740	0.552	4.789	0.748	5.296	0.985	5.733

5.

Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag
0.025	5.659	0.253	5.855	0.528	4.974	0.834	5.388
0.083	5.738	0.353	5.684	0.600	5.064	0.905	5.477
0.135	5.786	0.431	5.344	0.685	5.196	0.970	5.585
0.191	5.814	0.469	4.990	0.764	5.316		

6.

Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag
0.073	5.750	0.324	5.688	0.762	5.059	0.995	5.755
0.134	5.772	0.383	5.572	0.789	5.252		
0.196	5.779	0.458	5.257	0.818	5.416		
0.258	5.769	0.692	4.895	0.895	5.623		

10. RY Scorpii.

Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag
0.009	9.427	0.247	9.497	0.539	8.392	0.763	8.915
0.055	9.503	0.300	9.384	0.589	8.479	0.822	9.070
0.100	9.587	0.348	9.255	0.631	8.563	0.874	9.197
0.152	9.608	0.406	8.953	0.664	8.682	0.917	9.290
0.201	9.583	0.478	8.528	0.706	8.782	0.960	9.367

11. S Arae.

Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag
0.042	11.076	0.317	11.097	0.594	10.248	0.898	10.939
0.097	11.077	0.353	10.984	0.643	10.463	0.932	11.015
0.148	11.068	0.406	10.570	0.695	10.629	0.966	11.044
0.184	11.080	0.462	10.148	0.742	10.700	0.999	11.053
0.226	11.088	0.490	9.997	0.780	10.792		
0.271	11.089	0.543	10.100	0.838	10.863		

12. W Sagittarii

1.

Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag
0.032	6.038	0.300	6.112	0.587	5.072	0.796	5.484
0.075	6.130	0.356	5.748	0.639	5.196	0.852	5.524
0.149	6.205	0.452	5.184	0.703	5.284	0.916	5.646
0.239	6.253	0.537	4.936	0.757	5.372	0.982	5.865

TABLE V.—Normal Points for Twenty-four Cepheid Variables.—*Cont.*

Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
2.							
0.014	5.982	0.280	5.932	0.608	5.092	0.833	5.590
0.077	6.104	0.377	5.353	0.681	5.300	0.900	5.759
0.129	6.159	0.465	4.808	0.733	5.359	0.956	5.832
0.195	6.173	0.534	4.804	0.776	5.399		
3.							
0.012	5.985	0.332	5.794	0.553	4.892	0.879	5.606
0.073	6.064	0.375	5.465	0.601	5.045	0.951	5.887
0.141	6.102	0.434	5.144	0.657	5.189		
0.201	6.085	0.478	4.769	0.726	5.292		
0.271	6.038	0.510	4.712	0.803	5.368		
4.							
0.081	6.042	0.408	5.388	0.606	5.192	0.935	5.832
0.170	6.150	0.447	5.146	0.663	5.284	0.993	5.915
0.238	6.122	0.481	4.818	0.742	5.324		
0.298	5.969	0.518	4.734	0.828	5.512		
0.358	5.675	0.559	4.962	0.894	5.725		
5.							
0.019	5.910	0.278	6.029	0.475	4.784	0.704	5.452
0.075	5.952	0.341	5.727	0.527	4.789	0.766	5.477
0.138	6.022	0.385	5.451	0.577	5.080	0.844	5.616
0.213	6.122	0.423	5.154	0.637	5.318	0.939	5.804
6.							
0.036	5.920	0.272	5.953	0.565	4.919	0.822	5.465
0.088	6.019	0.352	5.656	0.615	5.250	0.868	5.560
0.139	6.070	0.434	5.032	0.700	5.406	0.925	5.729
0.192	6.060	0.522	4.677	0.775	5.428	0.981	5.842
13. AP Sagittarii.							
0.048	8.239	0.303	8.081	0.613	7.737	0.890	8.096
0.092	8.270	0.363	7.814	0.682	7.904	0.940	8.117
0.133	8.276	0.423	7.612	0.736	7.944	0.996	8.163
0.182	8.302	0.474	7.534	0.775	7.984		
0.221	8.309	0.522	7.585	0.817	8.048		
0.255	8.253	0.582	7.642	0.852	8.093		

TABLE V.—NORMAL POINTS FOR TWENTY-FOUR CEPHEID VARIABLES.—*Cont.*

Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
14. WZ Sagittarii.							
0.024	10.303	0.380	9.937	0.673	9.233	0.916	10.058
0.077	10.392	0.423	9.424	0.719	9.462	0.959	10.136
0.143	10.463	0.471	8.562	0.764	9.658	0.993	10.226
0.207	10.392	0.532	8.347	0.801	9.742		
0.278	10.233	0.576	8.677	0.838	9.808		
0.335	10.089	0.622	8.990	0.874	9.916		
15. XX Sagittarii.							
0.045	10.807	0.298	10.830	0.532	9.303	0.771	10.070
0.090	10.868	0.350	10.722	0.590	9.370	0.824	10.379
0.134	10.882	0.388	10.583	0.615	9.412	0.896	10.526
0.188	10.897	0.439	9.995	0.664	9.592	0.945	10.578
0.242	10.886	0.486	9.374	0.725	9.800	0.991	10.686
16. X Scuti.							
0.064	11.692	0.319	11.349	0.580	10.810	0.828	11.223
0.136	11.807	0.362	11.174	0.631	10.918	0.876	11.249
0.198	11.760	0.431	10.935	0.685	11.023	0.918	11.315
0.251	11.676	0.485	10.727	0.731	11.102	0.983	11.477
0.300	11.528	0.532	10.706	0.784	11.168		
17. U Sagittarii.							
0.019	8.878	0.317	8.945	0.603	8.082	0.921	8.733
0.056	8.953	0.380	8.673	0.655	8.160	0.975	8.797
0.107	9.043	0.447	8.375	0.701	8.310		
0.157	9.104	0.487	8.105	0.748	8.462		
0.202	9.070	0.521	8.002	0.799	8.566		
0.260	9.038	0.565	8.088	0.858	8.667		
18. Y Scuti.							
0.012	11.688	0.273	11.320	0.570	10.788	0.829	11.448
0.080	11.717	0.352	11.112	0.616	10.895	0.890	11.572
0.125	11.712	0.427	10.958	0.664	10.976	0.945	11.637
0.161	11.650	0.479	10.778	0.717	11.082		
0.207	11.588	0.520	10.713	0.772	11.257		
19. RU Scuti.							
0.009	11.750	0.339	11.740	0.591	10.838	0.819	11.348
0.069	11.785	0.383	11.591	0.631	10.944	0.851	11.502
0.143	11.798	0.420	11.242	0.671	11.049	0.889	11.631
0.218	11.806	0.475	10.704	0.717	11.139	0.946	11.696
0.279	11.808	0.537	10.537	0.771	11.233		

TABLE V.—NORMAL POINTS FOR TWENTY-FOUR CEPHEID VARIABLES.—*Cont.*

Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
20. Z Scuti.							
0.059	11.930	0.361	11.046	0.634	10.682	0.823	11.532
0.126	11.948	0.409	10.741	0.668	10.776	0.862	11.660
0.182	11.840	0.467	10.318	0.690	10.834	0.909	11.787
0.237	11.635	0.523	10.293	0.715	10.984	0.983	11.844
0.304	11.294	0.570	10.522	0.766	11.289		
21. SS Scuti.							
0.012	9.870	0.289	9.717	0.539	8.790	0.811	9.432
0.081	9.909	0.332	9.525	0.609	8.913	0.877	9.662
0.132	9.914	0.369	9.273	0.666	8.989	0.951	9.792
0.170	9.881	0.411	9.016	0.721	9.057		
0.225	9.820	0.465	8.790	0.769	9.185		
22. YZ Sagittarii.							
0.016	8.786	0.284	8.390	0.551	8.188	0.767	8.540
0.069	8.745	0.346	8.330	0.600	8.362	0.795	8.550
0.129	8.638	0.404	8.231	0.646	8.425	0.850	8.629
0.178	8.550	0.459	8.131	0.683	8.469	0.928	8.742
0.227	8.478	0.507	8.078	0.719	8.512	0.974	8.786
23. BB Sagittarii.							
1.							
0.032	8.466	0.333	8.190	0.606	7.660	0.898	8.386
0.083	8.576	0.388	7.918	0.673	7.879	0.954	8.403
0.145	8.604	0.442	7.656	0.721	8.198	0.996	8.393
0.197	8.568	0.493	7.606	0.765	8.292		
0.261	8.417	0.545	7.640	0.832	8.315		
2.							
0.039	8.462	0.280	8.256	0.570	7.656	0.822	8.192
0.078	8.540	0.346	7.927	0.634	7.835	0.872	8.289
0.118	8.580	0.399	7.732	0.675	7.929	0.905	8.295
0.168	8.605	0.449	7.690	0.710	7.966	0.941	8.381
0.222	8.508	0.509	7.622	0.765	8.060	0.990	8.410
3.							
0.008	8.438	0.300	8.201	0.548	7.676	0.819	8.169
0.065	8.574	0.345	7.970	0.501	7.748	0.875	8.210
0.112	8.603	0.388	7.770	0.656	7.926	0.942	8.282
0.151	8.591	0.430	7.636	0.693	8.096		
0.192	8.553	0.474	7.575	0.735	8.118		
0.246	8.445	0.512	7.574	0.777	8.118		

TABLE V.—Normal Points for Twenty-four Cepheid Variables.—*Cont.*

Phase	Mag.	Phase	Mag.	Phase	Mag.	Phase	Mag.
24. κ Pavonis.							
1.							
0.032	5.478	0.268	5.212	0.519	4.805	0.777	5.390
0.088	5.438	0.316	4.996	0.574	4.942	0.861	5.437
0.150	5.393	0.370	4.811	0.636	5.123	0.917	5.472
0.216	5.328	0.447	4.770	0.698	5.289	0.970	5.485
2.							
0.007	5.472	0.289	5.240	0.548	4.809	0.741	5.308
0.048	5.479	0.321	5.066	0.588	4.856	0.781	5.330
0.087	5.494	0.359	4.888	0.620	4.887	0.832	5.381
0.136	5.425	0.391	4.765	0.654	5.036	0.868	5.427
0.196	5.362	0.447	4.670	0.685	5.210	0.919	5.461
0.250	5.322	0.508	4.702	0.711	5.297	0.964	5.479
3.							
0.035	5.377	0.342	5.396	0.606	4.877	0.870	5.088
0.170	5.505	0.445	5.208	0.683	4.794		
0.257	5.485	0.532	5.016	0.754	4.853		

Proceedings of the American Academy of Arts and Sciences.

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RECORDS OF MEETINGS, 1928–1929, 1929–1930.

BIOGRAPHICAL NOTICES.

OFFICERS AND COMMITTEES FOR 1929–1930, 1930–1931.

LIST OF THE FELLOWS, ASSOCIATES, AND FOREIGN HONORARY MEMBERS.

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RECORDS OF MEETINGS

One thousand one hundred and sixth-seventh meeting

October 10, 1928.—Stated Meeting

The Academy met at its House at 8.30 P. M.

The President in the Chair.

There were present seventy-five Fellows and Associates and five guests.

The records of the Annual Meeting of May 9 were read and approved.

The Corresponding Secretary announced the receipt of letters accepting Fellowship from Adelbert Ames, Jr., J. P. Baxter, 3d, E. S. Brightman, J. W. M. Bunker, A. H. Cole, A. H. Compton, W. F. Dearborn, W. Y. Elliott, R. T. Fisher, L. J. Gillespie, C. H. Haring, R. G. Hoskins, W. L. Jepson, A. C. Knudson, W. T. Longcope, T. H. Morgan, W. L. Moss, J. H. Mueller, W. A. Nitze, Johnson O'Connor, C. H. Page, Langdon Pearse, R. B. Perry, W. M. Persons, George Scatchard, A. M. Schlesinger, J. F. Stevens, J. D. Tamarkin, Charles Terzaghi, M. S. Vallarta, H. B. Washburn, and Joshua Whatmough; of letters accepting Foreign Honorary Membership from F. A. Bather, H. L. Bergson, Benedetto Croce, Louis Dollo, Viscount Haldane, Edmund Husserl, Wolfgang Köhler, Mikinosuke Miyajima, Hanns Oertel, C. H. Ostenfelt, Friedrich Paschen, Karl Pearson, A. C. Pigou, C. Tate Regan, A. B. Rendle, S. P. L. Sörensen, and D. W. Thompson; of letters accepting Associate Membership from F. G. Balch, C. F. D. Belden, R. W. Boyden, F. P. Cabot, J. C. Cobb, Howard Coonley, W. L. W. Field, E. J. Holmes, R. L. O'Brien, A. S. Pier, A. L. Ripley, Odin Roberts, Jeremiah Smith, Jr., Payson Smith, Eliot Wadsworth, and E. A. Whitman; and of letters declining Associate Membership from the Earl of Camperdown and T. G. Frothingham.

The President announced the death of four Fellows:—Maurice Bloomfield (Class III, Section 2), Samuel Fessenden Clarke (Class II, Section 3), Pliny Earle Goddard (Class III, Section 2), John Warren (Class II, Section 4); and of two Foreign Honorary Members:—Viscount Haldane (Class III, Section 1), John Horne (Class II, Section 1).

The Fellows and Associates elected in May were then presented.

The following communication was presented:

Mr. George W. Pierce: "Some New Discoveries about Magnetostriction and the Possibility of its Application in the Industrial Arts."

Five papers were presented by title:

"The Compressibility and Pressure Coefficient of Resistance of Zirconium and Hafnium," by P. W. Bridgman.

"The Effect of Pressure on the Rigidity of Steel and Several Varieties of Glass," by P. W. Bridgman.

"The Effect of Pressure on the Resistance of Three Series of Alloys," by P. W. Bridgman.

"The Electrical Resistance of Alloys under Pressure," by C. W. Ufford. Presented by P. W. Bridgman.

"Thermo-Electric Phenomena and Electrical Resistance in Single Metal Crystals," by P. W. Bridgman.

The meeting was dissolved at ten o'clock.

One thousand one hundred and sixty-eighth meeting.

NOVEMBER 14, 1928.—STATED MEETING.

The Academy met at its House at 8.35 P. M.

The PRESIDENT in the Chair.

There were present fifty-three Fellows and Associates.

The records of the meeting of October 10 were read and approved.

The Corresponding Secretary reported for the Council the appointment of Lionel S. Marks to represent the Academy as delegate at the inauguration of Harvey Nathaniel Davis as President of the Stevens Institute of Technology.

The President announced the death of three Fellows: William Herbert Bixby (Class I, Section 4), Peter Schwamb (Class I, Section 4), and William Milligan Sloane (Class III, Section 3).

The following communication was presented:

Mr. William B. Munro: "Political Campaigns, Then and Now."

One paper was presented by title: "Table of Lagrangean Coefficients for Interpolating without Differences," by Edward V. Huntington.

The meeting was dissolved at 9.30 P. M.

One thousand one hundred and sixth-ninth meeting.

DECEMBER 12, 1928.—STATED MEETING.

The Academy met at its House at 8.40 P. M.

The PRESIDENT in the Chair.

There were present forty-three Fellows and Associates and twenty-seven guests, including ladies.

The meeting was preceded by a subscription dinner held in the Reading Room of the Academy. This was attended by thirty-eight Fellows and Associates and twenty-seven guests, including ladies.

The records of the meeting of November 14 were read and approved.

The Corresponding Secretary reported the receipt of a biographical memoir of William Otis Crosby, by A. C. Lane.

The President announced the death of three Fellows: Thomas Chrowder Chamberlin (Class II, Section 1), William North Rice (Class II, Section 1), and John Donnell Smith (Class II, Section 2).

The following communications were presented:

Dr. Walter B. Cannon: "Endocrine Factors in Relation to Physical Conditions."

Dr. Roy G. Hoskins: "Endocrine Factors in Personality Disorders."

The meeting was dissolved at ten o'clock.

One thousand one hundred and seventieth meeting.

JANUARY 9, 1929.—STATED MEETING.

The Academy met at its House at 8.20 P. M.

VICE-PRESIDENT Kennelly in the Chair.

There were present forty-one Fellows and Associates and five guests.

The records of the meeting of December 12 were read and approved.

The Corresponding Secretary reported the receipt of a letter from Thomas Nelson Perkins accepting his election as an Associate.

The Chair announced the death of John Merle Coulter, Fellow in Class II, Section 2.

The following communications were presented:

Mr. George D. Birkhoff: "Eastern and Western Music from a Mathematical Point of View."

Mr. Arthur N. Holcombe: "The Chinese Revolution."

The meeting was dissolved at 10.30 P. M.

One thousand one hundred and seventy-first meeting.

FEBRUARY 13, 1929.—STATED MEETING.

The Academy met at its House at 8.20 P. M.

VICE-PRESIDENT Parker in the Chair.

There were present twenty-two Fellows and two guests.

In the absence of the Recording Secretary, the Corresponding Secretary was asked to assume his duties.

The records of the meeting of January 9 were read and approved.

The Corresponding Secretary reported the receipt of a biographical memoir of George Washington Goethals, by I. N. Hollis.

He also announced that Professor William A. Setchell, of the University of California, had been appointed to represent the Academy at the Pacific Science Congress in Java, May 16–25, 1929.

A letter was read by the Corresponding Secretary from Edward H. Warren, resigning Fellowship because of residence hereafter in England.

The Treasurer called attention to the condition of the General Fund of the Academy, stating that the income from this Fund during the last eight years has not covered expenses, and that the contingent fund of 1912, by which the deficit has been met, is now nearly exhausted. A general discussion followed.

The Chair announced the death of three Fellows: Thomas Burr Osborne (Class I, Section 3), Frederick Cheever Shattuck (Class II, Section 4), and William Lyman Underwood (Class II, Section 3).

The following communication was presented:

Mr. George J. Peirce, Professor of Botany, Stanford University: "The Organisms in Brine Lakes."

The meeting was dissolved at 9.55 P. M.

One thousand one hundred and seventy-second meeting.

MARCH 13, 1929.—STATED MEETING.

The Academy met at its House at 8.20 P. M.

VICE-PRESIDENT Kittredge in the Chair.

There were present forty-two Fellows and Associates and ten guests.

The records of the meeting of February 13 were read and approved.

The Corresponding Secretary presented a letter from George Hunt Barton resigning Fellowship.

The Chair announced the death of the following Fellows: Charles Lemuel Nichols (Class III, Section 3) and Allyn Abbott Young (Class III, Section 3).

On recommendation of the Council the following appropriations were made for the ensuing year:

From the income of the General Fund, $7,775, to be used as follows:

for General and Meeting expenses	$1,000
for Library expenses	$2,000
for Books, Periodicals, and Binding	1,300
for House expenses	2,500
for Treasurer's expenses	975
	$7,775

From the Income of the Publication Fund, $4,209.50, to be used for publication.

From the income of the Rumford Fund, $6,303.51, to be used as follows:

for Research	$2,750.00
for Books, Periodicals, and Binding	200.00
for Publication	600.00
for use at the discretion of the Committee	2,753.51
	$6,303.51

From the income of the C. M. Warren Fund, $1,140, to be used at the discretion of the Committee.

The Chair announced the appointment of the Nominating Committee:

Harvey N. Davis, of Class I
Herbert V. Neal, of Class II
Edward W. Forbes, of Class III

The following communications were presented:

Mr. James Gray, Lecturer in Experimental Zoölogy, Cambridge University; "Ciliary Action as Studied by Moving Picture Methods," with moving picture illustrations.

Mr. G. H. Parker: "The Cilia of the Oviducts."

One paper was presented by title: "Alternating-Current Nets," by A. E. Kennelly.

The meeting was dissolved at 9.30 P. M.

One thousand one hundred and seventy-third meeting.

APRIL 10, 1929.—STATED MEETING.

The Academy met at its House at 8.15 P. M.

VICE-PRESIDENT Parker in the Chair.

There were present twenty-one Fellows.

In the absence of the Recording Secretary, the Corresponding Secretary was asked to assume his duties.

The records of the meeting of March 13 were read and approved.

From the Council the Corresponding Secretary announced the appointment of Mr. Curtis Hidden Page to be delegate of the Academy and to present an address at the 25th Anniversary of the American Academy of Arts and Letters in New York City on April 24 and 25.

The Chair announced the death of Charles Henry Brent, Fellow in Class III, Section 1, and of Ferdinand Foch, Foreign Honorary Member in Class I, Section 4.

Mr. Kennelly presented the report of the Committee on the Simplification of the Calendar, consisting of Messrs. Kennelly, O'Brien, Schlesinger, Shapley, and Whitman, appointed by the Council to consider two questions submitted by the National Committee on Calendar Simplification for the United States.

Upon recommendation of the Committee, it was

Voted, 1. That the Academy favors a change or simplification of the present calendar.

2. That the principle favored is that of thirteen months of twenty-eight days each.

Mr. Kennelly submitted a third question proposed in a more recent communication by the National Committee, and on motion it was

Voted, That the Academy approves the calling of an international conference, to be participated in by the United States, to consider the calendar question without being committed to any special principle of revision.

The following communication was presented:

Mr. Edward V. Huntington: "The Mathematical Aspects of the Problem of Reapportionment in Congress," with lantern illustrations.

The meeting was dissolved at 10.10 P. M.

One thousand one hundred and seventy-fourth meeting.

MAY 8, 1929.—ANNUAL MEETING.

The Academy met at its House at 8.20 P. M.

The PRESIDENT in the Chair.

There were present forty-six Fellows and Associates and two guests.

The records of the meeting of April 10 were read and approved.

The Corresponding Secretary announced the appointment of Willard L. Sperry and Edward C. Moore as delegates to the Fifth International Congress of the History of Religions at Lund, Sweden, August 27–29, 1929.

The following report of the Council was presented:

REPORT OF THE COUNCIL.

Since the last report of the Council there have been reported the deaths of seventeen Fellows: William Herbert Bixby, Maurice Bloomfield, Charles Henry Brent, Thomas Chrowder Chamberlin, Samuel Fessenden Clarke, John Merle Coulter, Pliny Earle Goddard, Charles Lemuel Nichols, Thomas Burr Osborne, William North Rice, Peter Schwamb, Frederick Cheever Shattuck, William Milligan Sloane, John Donnell Smith, William Lyman Underwood, John Warren, Allyn Abbott Young; and of three Foreign Honorary Members: Ferdinand Foch, Viscount Haldane, and John Horne.

Thirty-three Fellows, eighteen Foreign Honorary Members, and twenty-one Associates were elected by the Council and announced to the Academy in May 1928.

The roll now includes 580 Fellows, 81 Foreign Honorary Members, and 33 Associates (not including those elected in May 1929).

The annual report of the Treasurer, Ingersoll Bowditch, was read, of which the following is an abstract:

GENERAL FUND.

Receipts.

From Investments		$2,837.97	
From Assessments		3,720.00	
From Admissions		390.00	
From Interest on Deposits		209.75	
From Rumford Fund Income		200.00	
From Fund for Current Expenses		414.24	$7,771.96

Expenditures.

Expenses of Library	$2,042.00		
Treasurer's Expenses	825.97		
Books and Binding	1,138.06		
General Expenses	847.92		
House Expenses	2,323.98		
President's Expenses	4.45		
Biographical Notice	44.21	$7,226.59	
Transferred to Publication Fund	$250.00		
Income transferred to Principal	295.37	545.37	$7,771.96

RUMFORD FUND.

Receipts.

Income on hand April 1, 1928		$14,192.10	
From Investments	$4,443.37		
From Harvey N. Davis, unexpended grant returned	158.97	4,602.34	$18,794.44

Expenditures.

Purchase and Binding of Books	$292.25		
Publications	370.69		
Research	2,300.00		
Cases for Medals and Engraving	57.00		
Transferred to General Fund Income for care of books	200.00	$3,219.94	
Income transferred to Principal		10,210.42	$13,430.36

WARREN FUND.

Receipts.

Income on hand April 1, 1928		$934.51	
From Investments		1,188.00	$2,122.51

Expenditures.

Research	$2,000.00		
Vault Rent, part	3.00	$2,003.00	
Income transferred to Principal		59.20	$2,062.20

PUBLICATION FUND.

Receipts.

Income on hand April 1, 1928		$4,838.82	
From Income Appleton Fund	$1,590.98		
From Income Centennial Fund	2,448.82		
From Author's Reprints	868.73		
From Sale of Publications	666.21		
From General Fund Income	250.00	5,824.74	$10,663.56

Expenditures.

Publications	$3,867.33		
Vault Rent, part	10.00	$3,877.33	
Adjustment of Interest and Dividends on stock bought	2.54		
Income transferred to Principal	199.32	201.86	$4,079.19

FRANCIS AMORY FUND.

Receipts.

From Investments		$2,139.95

Expenditures.

Publishing Statement	$ 66.25	
Income transferred to Principal	2,073.70	$2,139.95

The following reports were also presented:

REPORT OF THE LIBRARY COMMITTEE.

During the year 118 volumes and 25 unbound numbers of periodicals have been borrowed by 20 Fellows and 13 libraries, and many more have been consulted at the Academy. All books taken out have been returned or satisfactorily accounted for.

The number of books on the shelves at the time of the last report was 41,239. During the year 402 volumes were added, making the number now 41,641. This includes 51 purchased from the General Fund, 35 from the Rumford Fund, and 316 received by gift or exchange. The number of pamphlets added was 115.

The following appropriations were placed at the disposal of the Committee during the past year:

Balance from General Fund	$ 340.21
Appropriation from General Fund	3,200.00
Balance from Rumford Fund	113.94
Appropriation from Rumford Fund	200.00
Total	$3,854.15

The expenses charged to the library during the financial year ending April 1, 1929, were:

Salaries		$2,000.00
Binding:		
General Fund	$543.05	
Rumford Fund	62.90	605.95

Purchase of Books and Periodicals:		
General Fund	$595.01	
Rumford Fund	229.35	824.36
Miscellaneous		42.00
Total		$3,472.31

There remained on April 1, 1929, an unexpended balance of $381.84, allocated as follows:

General Fund	$360.15
Rumford Fund	21.69

H. M. Goodwin, *Librarian.*

May 8, 1929.

Report of the Rumford Committee.

The Rumford Committee held five meetings during the academic year 1928–1929 (May 9, October 10, December 12, January 9, April 10).

The Committee made the following grants during the year, in aid of research in heat and light:—

1928

No. 270.	May 9	Dr. W. J. Luyten, Harvard College Observatory, for photographic supplies in research on stellar luminosities	$300
No. 271.	Dec. 12	Prof. P. W. Bridgman, Harvard University, for materials in investigations of thermal and optical properties of matter especially at high pressures	500
No. 272.	Dec. 12	Prof. Arthur H. Compton, the University of Chicago, for optical equipment in photographing tracks of beta rays excited by X-rays	500
No. 273.	Dec. 12	Prof. George W. Pierce, Harvard University, for equipment in research on light waves and electromagnetic waves	500

1929		
No. 274.	Jan. 9—Prof. H. T. Stetson, Harvard University, for apparatus in investigating effects of variation in solar radiation on ionisation of the earth's upper atmosphere . . .	300
	Total.	$2,100

Progress reports concerning researches aided by Rumford grants have been received from Messrs. R. T. Birge, P. W. Bridgman, A. H. Compton, J. C. Hubbard, N. A. Kent, G. W. Pierce, J. R. Roebuck and Harlow Shapley.

The following recent publications relate to researches that have been aided by Rumford grants:—

"Ionic Study of the Physical Properties of Liquids. The Velocity of Sound in Some Organic Liquids and their Compressibilities" by E. B. Freyer with J. C. Hubbard and Donald H. Andrews. Jour. of Am. Chem. Soc., Vol. 51, pp. 759–769, 1929.

"The compressibility of Several of the Elements" by P. W. Bridgman, Proc. Am. Ac. Arts & Sc., Vol. 62, No. 8.

"Thermoelectric Properties in Single Crystals" by P. W. Bridgman, Proc. Am. Ac. Arts & Sc., Vol. 63, No. 9.

"The Pressure Transitions of the Rubidium Halides" by P. W. Bridgman, Zeitschrift für Krystallographie, 1928. Vol. 67, p. 363.

"Intensity Relations in the Spectra of Titanium" by George R. Harrison, Jour. Optical Soc. of Am., Dec. 1928. Vol. 17, No. 6, pp. 389–416.

Respectfully submitted,
A. E. Kennelly, *Chairman.*

Report of the C. M. Warren Committee.

The Committee had at its disposal at the beginning of the fiscal year 1928–1929, $2,059.31, of which $886.24 was a balance from the previous year. Two thousand dollars ($2,000) have been appropriated during the year, leaving a balance of $59.31. The estimated available income for the year 1929–1930 is $1,184.00.

Since the last annual report grants have been made as follows:

May 21, 1928: to Dr. Charles F. H. Allen, Tufts College, $200, a renewal of a previous grant to continue his study of the addition reactions of Vinyl Phenyl Ketone.

May 21, 1928: to Professor Ben Corson, Middlebury College, $200, a renewal of a previous grant to continue his work on the Preparation of Malononitrile.

May 21, 1928: to Dr. Mary L. Sherrill, Mount Holyoke College, $600, for the experimental study of some unsaturated organic compounds from the standpoint of recent theories of atomic structure.

June 10, 1928: to Professor Avery A. Morton, Massachusetts Institute of Technology, $500, to aid him in the study of the addition of mercuric acetate to olefins.

October 4, 1928: to Professor Evald L. Skau, Trinity College, $200, to aid him in the study of melting points at low temperatures.

October 4, 1928: to Professor W. D. Bonner, University of Utah, $300, for the purchase of apparatus to be used in the precise measurement of boiling temperatures.

Reports of progress have been received from Professor Ben Corson, Professor Carl L. A. Schmidt, Professor Ralph H. Bullard, Professor Evald L. Skau, Dr. Charles F. H. Allen and Professor Avery A. Morton, and Professor Mary L. Sherrill.

The papers listed below, recently published, describe the results of investigations aided by the Warren Fund. In each case there is an acknowledgment by the author of the assistance received.

Ben B. Corson and Roger W. Stoughton—"Reactions of Alpha, Beta-Unsaturated Dinitriles," J. A. C. S., *50*, 2825 (1928).

"Preparation of Malononitrile" (Submitted to Organic Syntheses).

Carl L. A. Schmidt and Paul L. Kirk—"The Dissociation Constants of Certain Amino Acids," The Journal of Biological Chemistry, Vol. LXXXI, No. 2, February, 1929.

Ralph H. Bullard and Raymond A. Vingee—"Some Derivatives of Trimethylethylstannane," J. A. C. S., *51*, 892 (1929).

Evald L. Skau and Harry F. Meier—"The Transition Temperature of Carbon Tetrachloride as a Fixed Point in Thermometry." A Correction to an Article of this title by McCullough and Phipps. (Submitted to the Journal of the American Chemical Society.)

Dr. Charles F. H. Allen—Research on Vinyl Phenyl Ketone has been completed and the results embodied in a paper, submitted to the Journal of the American Chemical Society.

James F. Norris, *Chairman.*

Report of the Committee of Publication.

The sixty-third volume of the Proceedings is just finished. It contains eleven scientific papers, and the Records number; 524 pages in all.

There is on hand for publication three extensive memoirs on the language of the Paiute Indians by Professor E. Sapir of the University of Chicago. All of these memoirs are to be published as Proceedings and their publication will cost in the neighborhood of $6,000. They were submitted to us through Professor Franz Boas of Columbia University who will contribute $1,500 towards their publication in accordance with a letter received from him dated April 11, 1929.

We also have on hand for publication a paper by Professor A. E. Kennelly.

The available funds for next year are as follows:

Balance from previous year	$ 6,292.19
Appropriated for next year	4,209.50
Unexpended appropriation from the Rumford fund including an appropriation of $600 for next year	2,052.52
Contribution by Prof. Boas	1,500.00
Total	$14,054.21

Respectfully submitted,

Wm. S. Franklin, *Chairman.*

Report of the House Committee.

The House Committee has had funds at its disposal amounting to $3,477.61, made up as follows:

Balance from last year	$ 312.61
Appropriation for 1928–1929	2,850.00
Received for use of rooms	315.00
	$3,477.61

Of this amount, the sum of $2,518.68 has been spent for the usual routine expenses, janitor, light, power, heat, telephone, etc., and $120.30 has been spent for upkeep and equipment, making a total of $2,638.98, and leaving an unexpended balance of $838.63.

Meetings have been held as follows:

The Academy	8
American Antiquarian Society	1
American Ramabai Association	1
Archaeological Institute of America	1
Chamber Music Club	8
Circolo Italiano	1
Geological Society of Boston	2
Habit Clinic Committee	3
Harvard-Technology Chemical Club	7
Japan Society of Boston	1
Mediæval Academy of America	1
Musical Guild	2
National Women's Farm and Garden Association	1
New England Botanical Club	9
Radcliffe College Club	1
Saturday Morning Club	1
Zeta Phi Fraternity	1
	49

The Council Chamber has been used for Academy Council and Committee meetings, and also by the Trustees of the Children's Museum, the New England Farm and Garden Association, the Mediæval Academy of America, the Thursday Evening Club, etc.

A detailed list of expenditures follows:

Janitor		$ 974.00
Electricity	Light	190.06
	Power	78.20
Coal		931.00
Care of elevator		80.08
Gas		66.12

Water	39.36
Telephone	104.21
Ash tickets	30.15
Upkeep	62.20
Furnishings and equipment	58.10
Janitor's supplies and sundries	25.50
Total Expenditure	$2,638.98

S. B. Wolbach, *Chairman.*

May 8, 1929.

On the recommendation of the Treasurer, it was

Voted, That the Annual Assessment for 1929–1930 be $15.00.

The annual election resulted in the choice of the following officers and committees:

Edwin B. Wilson, *President*
Arthur E. Kennelly, *Vice-President for Class I*
George H. Parker, *Vice-President for Class II*
George L. Kittredge, *Vice-President for Class III*
Robert P. Bigelow, *Corresponding Secretary*
Charles B. Gulick, *Recording Secretary*
Ingersoll Bowditch, *Treasurer*
Harry M. Goodwin, *Librarian*
William S. Franklin, *Editor*

Councillors for Four Years.

Frederick A. Saunders, *of Class I* Charles T. Brues, *of Class II*
Irving Babbitt, *of Class III*

Councillor for One Year.

(To fill the unexpired term of E. H. Warren)
Edgar S. Brightman

Finance Committee.

Thomas Barbour Paul J. Sachs Frederick P. Fish

Rumford Committee.

Arthur E. Kennelly
Elihu Thomson
Harry M. Goodwin
Harlow Shapley
Percy W. Bridgman
Charles L. Norton
Frederick A. Saunders

C. M. Warren Committee.

James F. Norris
Gregory P. Baxter
Arthur D. Little
Reid Hunt
Walter L. Jennings
Frederick G. Keyes
Charles A. Kraus

Publication Committee.

(Editor) William S. Franklin, *ex officio Chairman*
Edwin C. Kemble, *of Class I*
Frederic T. Lewis, *of Class II*
George F. Moore, *of Class III*

Library Committee.

(Librarian) Harry M. Goodwin, *ex officio Chairman*
Raymond C. Archibald, *of Class I*
Thomas Barbour, *of Class II*
William C. Lane, *of Class III*

House Committee.

S. Burt Wolbach, *Chairman*
Robert P. Bigelow
William H. Lawrence

Committee on Meetings.

The President
The Recording Secretary
George H. Parker
Gregory P. Baxter
William C. Greene

Auditing Committee.

George R. Agassiz
John E. Thayer

The Corresponding Secretary reported that the following gentlemen had been elected members of the Academy by the Council:

FELLOWS.

Class I.

Section 1. Marston Morse, Cambridge.
Joseph Leonard Walsh, Cambridge.
Section 2. Clinton Joseph Davisson, New York, N. Y.
Arthur Cobb Hardy, Wellesley.
Section 3. James Alexander Beattie, Brookline.
Section 4. William Sowden Sims, Newport, R. I.
Arthur Edward Wells, Watertown.

Class II.

Section 1. Kirk Bryan, Cambridge.
Section 2. Joseph Horace Faull, Cambridge.
Ernest Henry Wilson, Jamaica Plain.
Section 3. Lemuel Roscoe Cleveland, Boston.
Hallowell Davis, Cambridge.
Joseph Grinnell, Berkeley, Calif.
Leigh Hoadley, Cambridge.
Section 4. James Bourne Ayer, Milton.
Edwin Allen Locke, Boston.

Class III.

Section 1. Clarence Irving Lewis, Cambridge.
Russell Henry Stafford, Brookline.
Section 4. Charles Townsend Copeland, Cambridge.
Edward Burlingame Hill, Cambridge.

FOREIGN HONORARY MEMBERS.

Class I.

Section 1. Willem de Sitter, Leyden.
Hermann Weyl, Zürich.
Section 2. Vilhelm Bjerknes, Oslo.
James Franck, Göttingen.
Abram F. Joffé, Leningrad.

Section 3. Johannes N. Brönsted, Copenhagen.
Heinrich Wieland, Munich.
Section 4. Ludwig Prandtl, Göttingen.
Emil Probst, Karlsruhe.
Aurel Stodola, Zürich.

Class II.

Section 1. Léon William Collet, Geneva.
Section 2. Otto Renner, Jena.
Section 4. Sir Robert Jones, Bart, Liverpool.
Sir Arnold Theiler, London.

Class III.

Section 1. Etienne Gilson, Melun, France.
The Marquess of Reading, London.
Section 4. Joseph Bédier, Paris.
Baron Charnwood, Lichfield.
Paul Hazard, Paris.

The following communication was presented:

Mr. Joshua Whatmough: "Who were the Indo-Europeans?"

The following papers were presented by title:

"On Signalling by Sound Waves," by G. W. Pierce.

"Experimental Measurements of the Velocity of Sound in Air at Ultra-Sonic Frequencies," by Charles D. Reid, presented by G. W. Pierce.

"Experiments Preliminary to a Measurement of the Velocity of Light, by Austin R. Frey, presented by G. W. Pierce.

"A Synopsis of the Crustacea Entomostraca of New England," by Charles H. Blake, presented by Robert P. Bigelow.

The meeting was dissolved at 9.55 P. M.

One thousand one hundred and seventy-fifth meeting.

October 9, 1929.—Stated Meeting.

The Academy met at its House at 8.15 P. M.

The President in the Chair.

There were present fifty-nine Fellows and Associates, one Foreign Honorary Member, and four guests.

In the absence of the Recording Secretary, the Corresponding Secretary was requested to assume his duties.

The records of the annual meeting of May 8 were read and approved.

The Corresponding Secretary reported the receipt of letters accepting Fellowship from J. B. Ayer, J. A. Beattie, Kirk Bryan, L. R. Cleveland, C. T. Copeland, Hallowell Davis, C. J. Davisson, J. H. Faull, Joseph Grinnell, A. C. Hardy, E. B. Hill, Leigh Hoadley, C. I. Lewis, E. A. Locke, Marston Morse, W. S. Sims, R. H. Stafford, J. L. Walsh, A. E. Wells, and E. H. Wilson; of letters accepting Foreign Honorary Membership from Joseph Bédier, V. F. K. Bjerknes, J. N. Brönsted, Baron Charnwood, L. W. Collet, James Franck, Etienne Gilson, Paul Hazard, A. F. Joffé, Sir Robert Jones, Ludwig Prandtl, Emil Probst, the Marquess of Reading, Otto Renner, Willem de Sitter, Aurel Stodola, Sir Arnold Theiler, Hermann Weyl, and Heinrich Wieland; and of a letter from Samuel Williston resigning Fellowship.

The Corresponding Secretary announced that Prof. Gilbert N. Lewis, of the University of California, had been appointed a delegate to represent the Academy in San Francisco, August 27 and 28, at the celebration of the 25th anniversary of the inauguration of research in terrestrial magnetism by the Carnegie Institution of Washington.

The President announced the death of two Fellows:—Charles Francis Brush (Class I, Section 4) and Frank Austin Gooch (Class I, Section 3); and of two Foreign Honorary Members:—Sir Edwin Ray Lankester (Class II, Section 3) and William Henry Perkin (Class I, Section 3).

The Fellows elected in May were then presented to the Academy.

Mr. J. D. M. Ford introduced Rector Henry Guy of the University of Grenoble, Foreign Honorary Member of the Academy, who addressed the Academy as its delegate to the Seventh Centenary of the University of Toulouse, from which he brought greetings and gifts, consisting of a medal and facsimiles of documents relating to the foundation of that university.

The following communication was presented:

Mr. Johnson O'Connor: "An Experiment in Measuring Aptitudes."

Four papers were presented by title:

"The Reflecting Power of Some Substances in the Extreme Ultra-Violet," by Paul R. Gleason, presented by Theodore Lyman.

"The Compressibility and Pressure Coefficient of Resistance of Several Elements and Single Crystals," by P. W. Bridgman.

"The Effect of Pressure on the Rigidity of Several Metals," by P. W. Bridgman.

"The Elastic Moduli of Five Alkali Halides," by P. W. Bridgman.

The meeting was dissolved at 9.45 P. M.

One thousand one hundred and seventy-sixth meeting.

NOVEMBER 13, 1929.—STATED MEETING.

The Academy met at its House at 8.40 P. M.

The PRESIDENT in the Chair.

There were present thirty-one Fellows and three guests.

On account of the illness of the Recording Secretary it was announced that Mr. J. D. M. Ford had been appointed Recording Secretary *pro tem.*

The records of the meeting of October 9 were read and approved.

The President announced that the Council on behalf of the Academy has entered into an agreement with the Boston Safe Deposit and Trust Company to act as the disbursing agent of the income of a Permanent Science Fund established by that company on September 5, 1928. For this purpose a Committee on the Permanent Science Fund has been appointed, with Dr. S. B. Wolbach as Chairman. The amount currently available for disbursement is estimated at about $2,700 a year, to be used in the aid of scientific research.

The Corresponding Secretary announced that the Council had approved a grant from the above of five hundred dollars to Dr. Harlow Shapley to be devoted to the employment of an experienced assistant in measuring periods and light curves of variable stars of the Cepheid class.

On behalf of the Council he also reported that Mr. Herbert V. Neal had been appointed Editor to fill the unexpired term of Mr. William S. Franklin, resigned.

The Corresponding Secretary reported the receipt of a letter from Mr. Wilbur C. Abbott, resigning Fellowship.

He also announced that the President had appointed Mr. Lionel S. Marks and Mr. Edward F. Miller to represent the Academy as delegates at the convocation in celebration of the 50th Anniversary of the American Society of Mechanical Engineers.

The President announced the death of two Fellows: George Angier Gordon (Class III, Section 1) and Moorfield Storey (Class III, Section 1).

The following communication was presented:

Mr. John G. Jack: "The Study of Trees."

One paper was presented by title: "The Minimum of Resistance of High Pressure," by P. W. Bridgman.

The meeting was dissolved at 9.55 P. M.

One thousand one hundred and seventy-seventh meeting.

DECEMBER 11, 1929.—STATED MEETING.

The Academy met at its House at 8.25 P. M.

The PRESIDENT in the Chair.

There were present fifty-five Fellows and Associates and three guests.

The records of the meeting of November 13 were read and approved.

The Corresponding Secretary reported the receipt of a letter from Dr. David L. Edsall, resigning Fellowship.

It was *Voted,* To adopt the recommendation in the following report presented by the Chairman of the committee, Mr. Edwin H. Hall:

"The Committee for the Procurement of Biographical Notices recommends to the Academy that in the case of a deceased Foreign Honorary Member the biographical notice shall ordinarily be of a purely formal character, similar to the notice presented to the Academy at the time of his election, and that such a notice shall be prepared under the direction of the Corresponding Secretary."

Professor Charles R. Lanman then introduced the speaker of the evening, Sir Aurel Stein.

The subject of the communication was: "The Campaign of Alexander the Great on the Northwest Frontier of India," illustrated by lantern slides.

The meeting was dissolved at 9.45 P. M.

One thousand one hundred and seventy-eighth meeting.

JANUARY 8, 1930.—STATED MEETING.

The Academy met at its House at 8.28 P. M.

The PRESIDENT in the Chair.

There were present thirty-nine Fellows and Associates and nine guests.

The records of the meeting of December 11 were read and approved.

The Corresponding Secretary announced the resignation of Mr. Charles B. Gulick as Recording Secretary and also as a delegate of the Academy to the American Council of Learned Societies; and the appointment by the Council of Mr. J. D. M. Ford as delegate to the American Council for a term of four years.

He also reported the receipt of a letter from Langdon Warner, resigning Fellowship; and of a biographical memoir of Addison Emery Verrill, by Charles Schuchert.

It was announced that Messrs. J. D. M. Ford and Albert Sauveur had been appointed delegates to represent the Academy at the inauguration of new buildings at the University of Brussels, on June 23–25, 1930.

The President announced the death of William Rosenzweig Arnold, (Class III, Section 2) and of George Edward Woodberry, (Class III, Section 4).

He also urged the Fellows to send in nominations to membership before February 15.

The following communication was presented:

Dr. Joseph W. Schereschewsky: "The Present Status of the Cancer Problem."

The meeting was dissolved at 9.46 P. M.

One thousand one hundred and seventy-ninth meeting.

FEBRUARY 12, 1930.—STATED MEETING.

The Academy met at its House at 8.30 P. M.

The PRESIDENT in the Chair.

There were present thirty-one Fellows and Associates and ten guests.

The records of the meeting of January 8 were read and approved.

The Corresponding Secretary reported that the Council had appointed Mr. J. D. M. Ford, Recording Secretary, to fill out the term of Mr. Charles B. Gulick, who had resigned.

The President announced the death of Edward Waldo Emerson, Fellow in Class III, Section 4.

The President called attention to the fact that nominations to membership in certain sections of Class III were needed.

On the recommendation of the Rumford Committee, it was

Voted, To award the Rumford Premium to John Stanley Plaskett, Director of the Dominion Astrophysical Observatory, Victoria, B. C., for his stellar spectrographic researches.

The following communication was presented:

Mr. J. Stanley Gardiner, M.A., F.R.S., Professor of Zoölogy and Comparative Anatomy in the University of Cambridge: "Coral Reefs."

One paper was presented by title: "The New World Species of the Genus *Solenopsis*," by William S. Creighton, presented by C. T. Brues.

The meeting was dissolved at 9.45 P. M.

One thousand one hundred and eightieth meeting

MARCH 12, 1930.—STATED MEETING.

The Academy met at its House at 8.38 P. M.

The PRESIDENT in the Chair.

There were present forty-six Fellows and Associates and four guests.

The records of the meeting of February 12 were read and approved.

The Corresponding Secretary reported the receipt of a biographical memoir of William Herbert Bixby, by E. H. Hall: and of a letter from Clarence Henry Haring, resigning Fellowship.

He also announced the appointment of William B. Munro as delegate of the Academy at the dedication of the new campus and buildings of the University of California, March 27 and 28, at Los Angeles.

On behalf of the Council the Corresponding Secretary announced a grant from the income of the Permanent Science Fund of $600. to Prof. Charles T. Brues for the purchase of photographic equipment and materials to aid in a study of the movements of insects.

The President announced the death of three Fellows:—Arthur Twining Hadley (Class III, Section 3), Hector James Hughes (Class I, Section 4), and William Howard Taft (Class III, Section 1); and of one Foreign Honorary Member, Karl Friedrich Geldner (Class III, Section 2).

On recommendation of the Council the following appropriations were made for the ensuing year:

From the income of the General Fund, $7,875, to be used as follows:

for General and Meeting expenses	$1,000
for Library expenses	2,100
for Books, Periodicals, and Binding	1,300
for House expenses	2,500
for Treasurer's expenses	975
	$7,875

From the income of the Publication Fund, $4,235.57, to be used for publication.

From the income of the Rumford Fund, $4,320.37, to be used as follows:

for Research	$2,750.00
for Books, Periodicals, and Binding	300.00
for Publication	600.00
for use at the discretion of the Committee	670.37
	$4,320.37

From the income of the C. M. Warren Fund, $1,193.25, to be used at the discretion of the Committee.

The President appointed the Nominating Committee as follows:

Harlow Shapley, *of Class I.*
Louis C. Graton, *of Class II.*
Edgar S. Brightman, *of Class III.*

The following communication was presented:

Dr. William L. Moss: "With Cannibals and Head-Hunters."

One paper was presented by title: "The Anonymous La Conquista Del Peru (Seville, April 1534) and the Libro Vltimo Del Svmmario

Delle Indie Occidentali (Venice, October 1534)," by Alexander Pogo, presented by J. D. M. Ford.

The meeting was dissolved at 9.39 P. M.

One thousand one hundred and eighty-first meeting.

APRIL 9, 1930.—STATED MEETING.

The Academy met at its House at 8.38 P. M.

The PRESIDENT in the Chair.

There were present forty-one Fellows and Associates and twelve guests.

In the absence of the Recording Secretary Mr. Walter E. Clark was asked to assume the duties of his office.

The records of the meeting of March 12 were read and approved.

The Corresponding Secretary announced that the Council on behalf of the Academy had ratified the constitution of the American Council of Learned Societies as amended at its meeting of January 11, 1930.

He also reported that Mr. Dayton C. Miller had been appointed delegate of the Academy at the semi-centennial of the Case School of Applied Science and inauguration of President Wickenden on April 11; and that Mr. Richard C. Tolman had been appointed to represent the Academy at the semi-centennial of the University of Southern California to be held at Los Angeles on June 4, 5, and 6.

The President announced the death of two Fellows:—Claude Halstead Van Tyne (Class III, Section 3) and Winslow Warren (Class III, Section 1); and of one Foreign Honorary Member, Arthur James Balfour, Earl of Balfour (Class III, Section 1).

The Rumford Medals were presented by the President to Dr. John Stanley Plaskett, Director of the Dominion Astrophysical Observatory, Victoria, B. C., for his stellar spectrographic researches, after Professor Arthur E. Kennelly, Chairman of the Rumford Committee, had made a statement in regard to the Rumford Premium and its recipient.

The following communication was presented:

Mr. John Stanley Plaskett: "The Gases of Interstellar Space."

The meeting was dissolved at 9.54 P. M.

One thousand one hundred and eighty-second meeting.

MAY 14, 1930.—ANNUAL MEETING.

The Academy met at its House at 8.35 P. M.

The PRESIDENT in the Chair.

There were present thirty-three Fellows and five guests.

The records of the meeting of April 9 were read and approved.

The Corresponding Secretary reported the receipt of biographical memoirs of William Rosenzweig Arnold, by J. R. Jewett, of William Sturgis Bigelow, by Arthur Fairbanks, of Maurice Bloomfield, by Franklin Edgerton, of Archibald Cary Coolidge, by W. S. Ferguson, of Pliny Earle Goddard, by R. B. Dixon, of George Angier Gordon, by F. G. Peabody, of Okakura-Kakuzo, by W. S. Bigelow and J. E. Lodge, of Theodore William Richards, by G. S. Forbes, and of Allyn Abbott Young, by F. W. Taussig.

He also announced that at the inauguration of Homer LeRoy Shantz as President of the University of Arizona on April 24 the Academy was represented by William M. Davis.

On behalf of the Council the Corresponding Secretary made the following announcements:

The Librarian has announced to the Council a gift to the Academy from Professor Arthur E. Kennelly of eight valuable sets of journals comprising in all 224 volumes. These will materially add to the completeness of the library, particularly in the field of radio and electrical engineering. The Council has voted to Mr. Kennelly the thanks of the Academy for this valuable gift.

A committee appointed by the President, with Mr. Goodwin as chairman, to confer with a committee of the Boston Society of Natural History, has reported that the two committees have met in joint session and have approved a plan for extending the use of the reading room and facilities of the library of each society to members of the other. It was recommended that persons desiring to use the library of the society of which they are not members, should present a card of introduction to the Librarian or his representative.

The extent of unnecessary duplication of accessions to the two libraries and how it may be reduced are questions to be considered by the committee upon the completion of a list now in preparation by the Boston Society of Natural History. In the meantime, it is understood that reciprocal library privileges to members of the two societies will become operative.

The Council has adopted this report and has received notice of similar action by the Trustees of the Boston Society of Natural History.

It was announced that the Council had made the following grants from the Permanent Science Fund:

1. To Harlow Shapley, $1,000, for the employment of an expert assistant in a systematic study of eclipsing binaries by means of the Harvard plates.
2. To C. I. Reed, $500, for use in a study of the influence of irradiated ergosterol on metabolism.
3. To J. Leroy Conel, $500, to be used for the collection of embryos of the hagfish, *Bdellostoma stouti*, necessary for the completion of researches on the development of the brain.

On the recommendation of the Council the Academy then passed a vote of thanks to Mr. Bernard A. Behrend for his gift of a large portrait in oil of Thomas Henry Huxley, painted by the Hon. John Collier.

The President announced the death of two Fellows:—Horace Howard Furness, Jr. (Class III, Section 4) and William Edward Story (Class I, Section 1).

He also called attention to the fact that the Academy is 150 years old this month, its charter having been granted on May 4, 1780, and the first meeting held on May 30, 1780.

The following report of the Council was presented:

REPORT OF THE COUNCIL.

Since the last report of the Council there have been reported the deaths of fourteen Fellows: William Rosenzweig Arnold, Charles Francis Brush, Edward Waldo Emerson, Horace Howard Furness, Jr., Frank Austin Gooch, George Angier Gordon, Arthur Twining Hadley, Hector James Hughes, Moorfield Storey, William Edward Story, William Howard Taft, Claude Halstead Van Tyne, Winslow Warren, George Edward Woodberry; and of four Foreign Honorary Members: The Earl of Balfour, Karl Friedrich Geldner, Sir Edwin Ray Lankester, William Henry Perkin.

Twenty Fellows and nineteen Foreign Honorary Members were elected by the Council and announced to the Academy in May 1929.

The roll now includes 579 Fellows, 96 Foreign Honorary Members, and 33 Associates (not including those elected in May 1930).

The annual report of the Treasurer, Ingersoll Bowditch, was read, of which the following is an abstract.

GENERAL FUND.

Receipts.

From Investments		$3,052.33	
From Assessments		5,505.00	
From Admissions		180.00	
From Interest on Deposits		363.45	
From Rumford Fund Income		200.00	$ 9,300.78

Expenditures.

Expenses of Library	$2,104.45		
Treasurer's Expenses	976.72		
Books and Binding	933.71		
General Expenses	885.57		
House Expenses	2,500.86		
President's Expenses	2.10	$7,403.41	
Income transferred to Principal		362.52	$ 7,765.93

RUMFORD FUND.

Receipts.

Income on hand April 1, 1929		$5,364.08	
From Investments		4,672.72	$10,036.80

Expenditures.

Purchase and Binding of Books	$ 335.45		
Research	1,815.43		
Medals	313.80		
Transferred to General Fund Income for care of books	200.00	$2,664.68	
Interest on bonds bought	$ 117.93		
Income transferred to Principal	216.79	334.72	$ 2,999.40

WARREN FUND.

Receipts.

Income on hand April 1, 1929		$ 60.31	
From Investments		1,228.75	$ 1,289.06

Expenditures.

Research	$1,150.00		
Vault Rent—part	3.00	$1,153.00	
Income transferred to Principal		60.00	$ 1,213.00

PUBLICATION FUND.

Receipts.

Income on hand April 1, 1929		$6,584.37	
From Income Appleton Fund	$1,662.50		
From Income Centennial Fund	2,586.50		
From Authors' Reprints	141.55		
From Sale of Publications	665.03	5,055.58	$11,639.95

Expenditures.

Publications	$1,683.07		
Vault Rent—part	10.00	$1,693.07	
Interest on Bonds bought	$ 87.22		
Charged to cancel premium on Bonds	28.00		
Income transferred to Principal	206.18	321.40	$ 2,014.47

FRANCIS AMORY FUND.

Receipts.

From Investments		$ 2,208.00

Expenditures.

Publishing Statement	$ 70.40	
Income transferred to Principal	2,137.60	$ 2,208.00

PERMANENT SCIENCE FUND.

Receipts.

Received for above fund	$ 1,739.42

Expenditures.

Grants from above fund	$ 1,100.00

The following reports were also presented:

REPORT OF THE LIBRARY COMMITTEE.

During the year 127 volumes and 18 unbound numbers of periodicals have been borrowed by 15 Fellows and 10 libraries, and many more have been consulted at the Academy. All books taken out have been returned or satisfactorily accounted for.

The number of books on the shelves at the time of the last report was 41,641. During the year 385 volumes were added, making the number now 42,026. This includes 33 purchased from the General Fund, 19 from the Rumford Fund, and 333 received by gift or exchange. The number of pamphlets added was 95.

During the year three sets of periodicals, the Central-Zeitung für Optik und Mechanik, Nouvelles Annales de Mathématiques, and Scientia, were sold upon the recommendation of the Library Committee, and the proceeds added to the library fund.

The following appropriations were placed at the disposal of the Committee during the past year:

Balance from General Fund	$ 360.15
Appropriation from General Fund	3,300.00
Sale of Periodicals	280.00
Balance from Rumford Fund	21.69
Appropriation from Rumford Fund	400.00
	$4,361.84

The expenses charged to the Library during the financial year ending April 1, 1930, were:

Salaries	$2,000.00

Binding:	
General Fund	579.50
Rumford Fund	78.00
Purchase of Books and Periodicals:	
General Fund	634.21
Rumford Fund	257.45
Miscellaneous	104.45
Total	$3,653.61

There remained on April 1, 1930, an unexpended balance of $708.23, allocated as follows:

General Fund	$621.99
Rumford Fund	86.24

The Library has recently received from Professor Arthur E. Kennelly the valuable gift of eight sets of journals comprising in all 224 volumes. This acquisition will very materially increase the value of the Library for reference in the fields of radio and electrical engineering.

During the past year the Council has extended the privilege of consulting the Library and using the Reading Room to members of the Boston Society of Natural History, similar privileges being offered to members of the Academy by the Society. A special committee appointed by the President and a corresponding committee representing the Boston Society of Natural History, have at present under consideration plans for further co-operation between the libraries of the two institutions in matters pertaining to the purchase and acquisition of books and periodicals.

H. M. Goodwin, *Librarian.*

May 14, 1930.

Report of the Rumford Committee.

The Rumford Committee held seven meetings during the academic year 1929–1930 (May 8, Nov. 13, Dec. 11, Jan. 8, Feb. 12, March 12, and April 9).

The Committee made the following grants from the Rumford Fund, during the year, in aid of researches on heat and light:—

	1929		
No. 275.	May 9	—Prof. E. L. Chaffee, Harvard University, for equipment in research on electrical responses of the retina to light	$100
No. 276.	Nov. 12	—Prof. George R. Harrison, Stanford University, for equipment in research on spectrophotometry	300
No. 277.	Nov. 12	—Dr. Annie J. Cannon, Harvard Observatory, towards purchase of an objective prism for stellar spectrophotographic research	500
No. 278.	Dec. 11	—Prof. Harlan T. Stetson, Ohio Wesleyan University, Delaware, Ohio, for purchase of equipment in solar radiation researches	200
	1930		
No. 279.	Feb. 12	—Dr. Norman Feather, Johns Hopkins University, for purchase of equipment in radio absorption	500
No. 280.	Feb. 12	—Prof. H. H. Plaskett, Harvard Observatory, for purchase of equipment in researches on astrophotometry	500
No. 281.	Mar. 12	—Prof. P. W. Bridgman, Harvard University, for purchase of equipment in researches on thermal and optical properties of matter	500
No. 282.	Mar. 12	—Prof. D. C. Stockbarger, Mass. Inst. of Technology, Cambridge, for purchase of equipment in researches in spectrophotometry	500
No. 283.	Apr. 9	—Dr. G. H. Dieke, Johns Hopkins University, for equipment in spectrophotographic research (confirmation of action taken March 12)	300
		Total	$3,400

The Committee voted unanimously, first on January 8, and again on February 12, 1930, to recommend the award of the Rumford Premium to Dr. John Stanley Plaskett, Director of the Dominion Astrophysical Observatory at Victoria, B. C. "for stellar spectrographic researches." The medals were presented to Dr. Plaskett by the President of the Academy at the meeting of April 9.

Reports of progress in researches conducted with the aid of grants from the Rumford Fund have been received from Messrs. S. Albrecht, R. T. Birge, A. H. Compton, J. C. Hubbard, G. W. Pierce, and H. Shapley.

The following recent publications concern researches that have been aided by grants from the Rumford Fund:

By Prof. George R. H. Harrison, Stanford University:

(1) "Intensity Relations in the Spectra of Titanium," and "Relative Intensities of the Stronger Multiplets of TI I," with Harry Engwicht. *The Journ. of the Optical Soc. of America* and *Review of Scientific Insts.*, Vol. 18, No. 4, April 1929, pp. 287–301.

(2) "On the Elimination of Errors when Wire Screens are Used as Neutral Filters for Photographic Photometry," same journal as No. 1. Vol. 18, No. 6, June, 1929, pp. 492-502.

(3) "Intensity Relations in the Spectra of Titanium III. Intensities in Super-Multiplets of TI I," same journal, Vol. 19, No. 3, Sept. 1929, pp. 109–133.

(4) "Instruments and Methods Used for Measuring Spectral Light Intensities by Photography," same journal, Vol. 19, No. 5, Nov. 1929, pp. 267–316.

By P. W. Bridgman, Harvard University:

(5) "The Compressibility and Pressure Coefficient of Resistance of Several Elements and Single Crystals." *Proc. Am. Ac. of Arts and Sciences*, Vol. 64, No. 4, December 1929, pp. 51–73.

By Paul Kirkpatrick and Iwao Miyake, University of Hawaii:

(6) "Polarization of the Tungsten L Radiations." *Proc. National Ac. of Sciences*, Vol. 15, No. 5, May 1929, pp. 418–421.

By Paul Kirkpatrick, University of Hawaii:

(7) "Classical Scattering in X-ray Reflection." *Journ. of the Optical Soc. of America and Rev. of Sc. Insts.*, Vol. 18, No. 6, June 1929, pp. 452–458.

Respectfully Submitted,

A. E. Kennelly, *Chairman.*

May 14. 1930.

Report of the C. M. Warren Committee.

The Committee had at its disposal at the beginning of the fiscal year 1929–1930, $1,199.31, of which $1,150.00 have been appropriated during the past year.

Since the last annual report grants have been made as follows:

June 3, 1929: to Professor Allen B. Stowe, Kalamazoo College, $300, to be used in connection with his work on the solubilities of salts in non-aqueous solvents.

June 3, 1929: to Professor Avery A. Morton, Massachusetts Institute of Technology, $500, to aid him in the study of the preparation and properties of certain olefins heretofore not well characterized.

June 3, 1929: to Professor Samuel P. Mulliken, Massachusetts Institute of Technology, $350, to be used to cover the cost of the preparation of certain rare hydrocarbons.

Reports of Progress have been received from Charles F. H. Allen, R. H. Bullard, Henry Gilman, S. P. Mulliken, and M. L. Sherrill.

The papers listed below, which have been published since the last report of the Committee, describe the results of investigations aided by the Warren Fund. In each case there is an acknowledgment by the author of the assistance received.

Charles F. H. Allen and M. Philbrick Bridgess: "Addition Reactions of Vinyl Phenyl Ketone. I. Phenylnitromethane, J. A. C. S. *51*, 2151 (1929).

Charles F. H. Allen and Ernest F. Herrmann: "The Bromination of Desylacetophenone," J. A. C. S. *51*, 3591 (1929).

Ralph H. Bullard and Alfred C. Haussmann: "The Vapor Pressure of Some Stannanes," Journal of Physical Chemistry, Vol. XXXIV, pp. 743–747, April, 1930.

Ralph H. Bullard: "A Series Arrangement of Organic Groups. I. As Determined by the Halogenation of Mixed Stannanes," J. A. C. S. *51*, 3065 (1929).

Henry Gilman, J. McGlumphy and R. E. Fothergill: "The Luminescence Resulting from Some Aryl-Magnesium Halides with Nitro Compounds." (Preprint of a paper to be published in the Rec. trav. Chim. in April or May of this year).

Carl L. A. Schmidt, W. K. Appleman, and Paul L. Kirk: "The Apparent Dissociation Constant of Tryptophane and of Histidine," The Journal of Biological Chemistry, Vol. LXXXV, No. 1, December, 1929.

J. Errera and M. L. Sherrill: "Dipolemoments and Molecular Constitution," Leipziger Vorträge, Page 41, 1929.

Arthur F. Scott and Clyde R. Johnson: "The Atomic Weight of Chlorine. The Ratio $NOCl:Ag$," Journal of Physical Chemistry, Vol. XXXIII, pp. 1975–1986, December, 1929.

James F. Norris, *Chairman.*

May 14, 1930.

Report of the House Committee.

The House Committee has had funds at its disposal amounting to $3,648.63, made up as follows:

Balance from previous year	$ 838.63
Appropriation for 1929–30	2,500.00
Received for use of rooms	310.00

Of this amount, the sum of $2,533.01 has been spent for the routine expenses, janitor, light, power, heat, telephone, etc., and $277.85 has been spent for upkeep and equipment, making a total of $2,810.86, and leaving an unexpended balance of $837.77. The chief item of upkeep this year has been renovating and repairing the Reading Room chairs and other furniture. Our appropriation for the coming year includes a sum for painting the lecture hall and the staircase hall, which work we expect to have done this summer.

Meetings have been held as follows:

The Academy	8
American Antiquarian Society	1
Am. Chemical Society, Northeastern Section	7
Archaeological Institute of America	3
Harvard-Technology Chemical Club	7
Japan Society of Boston	2
Mediaeval Academy of America	1
Musical Guild of Boston	2
Needlework Guild, N. E. Labrador Branch	1
New England Botanical Club	9
Radcliffe Club of Boston	1
Thursday Evening Club	1
	43

The Council Chamber had been used for Academy Council and Committee meetings, and also by the Trustees of the Children's Museum, the New England Farm and Garden Association, the Thursday Evening Club, etc.

A detailed list of expenditures follows:

Janitor		$ 986.00
Electricity	Light	197.02
	Power	101.88
Coal		896.90
Care of elevator		73.79
Gas		48.46
Water		46.00
Telephone		106.21
Ash tickets		30.15
Upkeep		256.25
Furnishing and equipment		21.60
Janitor's supplies and sundries		46.60
Total expenditure		$2,810.86

S. B. Wolbach, *Chairman.*

May 14, 1930.

Owing to the absence from the country of the Editor, no report of the Publication Committee was presented at this time.

It was *Voted,* To confirm the award of the Rumford Premium to Dr. John S. Plaskett, previously voted at the February meeting.

On the recommendation of the Treasurer, it was *Voted,* That the Annual Assessment for 1930–1931 be $15.

The annual election resulted in the choice of the following officers and committees:

EDWIN B. WILSON, *President.*
HARRY M. GOODWIN, *Vice-President for Class I.*
GEORGE H. PARKER, *Vice-President for Class II.*
JEREMIAH D. M. FORD, *Vice-President for Class III.*
TENNEY L. DAVIS, *Corresponding Secretary.*
WALTER E. CLARK, *Recording Secretary.*
INGERSOLL BOWDITCH, *Treasurer.*
ALFRED C. LANE, *Librarian.*
HERBERT V. NEAL, *Editor.*

Councillors for Four Years.

CLARENCE L. E. MOORE, *of Class I.* HERVEY W. SHIMER, *of Class II*
ALBERT C. KNUDSON, *of Class III.*

Finance Committee.

THOMAS BARBOUR	PAUL J. SACHS	FREDERICK P. FISH

Rumford Committee.

	ARTHUR E. KENNELLY	
ELIHU THOMSON	HARRY M. GOODWIN	HARLOW SHAPLEY
PERCY W. BRIDGMAN	CHARLES L. NORTON	NORTON A. KENT

C. M. Warren Committee.

	JAMES F. NORRIS	
GREGORY P. BAXTER	ARTHUR D. LITTLE	REID HUNT
WALTER L. JENNINGS	FREDERICK G. KEYES	CHARLES A. KRAUS

Publication Committee.

(Editor) Herbert V. Neal, *ex officio Chairman*
Edwin C. Kemble, *of Class I* Frederic T. Lewis, *of Class II*
George F. Moore, *of Class III*

Library Committee.

(Librarian) Alfred C. Lane, *ex officio Chairman*
Raymond C. Archibald, *of Class I* Thomas Barbour, *of Class II*
William C. Lane, *of Class III*

House Committee.

S. Burt Wolbach, *Chairman*
Robert P. Bigelow William H. Lawrence

Committee on Meetings.

The President
The Recording Secretary
George H. Parker Daniel F. Comstock William C. Greene

Auditing Committee.

George R. Agassiz John E. Thayer

The Corresponding Secretary reported that the following gentlemen had been elected members of the Academy by the Council:

FELLOWS.

Class I.

Section 1. Philip Franklin, Belmont.
Harry Hemley Plaskett, Cambridge.
Dirk Jan Struik, Cambridge.
Section 3. Lafayette Benedict Mendel, New Haven, Conn.
Lyman Churchill Newell, Brookline.
Section 4. Frank Baldwin Jewett, New York, N. Y.
Greenleaf Whittier Pickard, Newton Center.
George Edmond Russell, Arlington.

CLASS II.

Section 2. LeRoy Abrams, Stanford University, Cal.
Karl Sax, Boston.
Section 3. Henry Clinton Fall, Tyngsboro.
Section 4. David Cheever, Boston.
Torald Hermann Sollmann, Cleveland, Ohio.
Fritz Bradley Talbot, Brookline.

CLASS III.

Section 1. Thomas Hovey Gage, Worcester.
William Henry Paine Hatch, Cambridge.
James Hugh Ryan, Washington, D. C.
George Augustus Sanderson, Littleton.
Section 2. James Geddes, Jr., Brookline.
Ernest Hatch Wilkins, Oberlin, Ohio.
Section 4. John Erskine, New York, N. Y.

FOREIGN HONORARY MEMBERS.

CLASS I.

Section 3. Archibald Byron Macallum, London, Ontario.

CLASS II.

Section 3. Louis Édouard Lapicque, Paris.

CLASS III.

Section 2. Sir Aurel Stein, Srinagar, Kashmir.
Section 4. Alfredo Casella, Rome.

The following communication was presented:

Dr. William B. Castle: "The Etiology of Pernicious Anemia."

The following paper was presented by title: "Photographic Investigation of 24 Southern Cepheid Variable Stars," by Harlow Shapley.

The meeting was dissolved at 10.17 P. M.

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WILLIAM ROSENZWEIG ARNOLD[1] (1872–1929).

Fellow in Class III, Section 2, 1914.

William Rosenzweig Arnold was born of German parents, November 14, 1872, and died at his home in Cambridge on December 11, 1929.

He was taken as a very young boy to Jerusalem, and many of his boyish memories centered around the Holy City. Moving later to Egypt, he spent several years in Alexandria and came to America when he was about fourteen years of age. That he was not slow to learn is shown by the fact that after preparing for the Ohio Wesleyan University at Delaware, Ohio, he graduated from that institution in his twentieth year in 1892. His college course was followed by studies in Union Theological Seminary, from which he was graduated in 1895. During the college year 1895–96 he was University Fellow in Columbia University, where he was awarded his Ph.D in 1896. His thesis was entitled Ancient-Babylonian Temple Records. In the years 1896–98 he was Curator of the Department of Antiquities in the Metropolitan Museum of Art, New York. He could have continued in Museum work had he so wished, but he decided to turn to scholarly work of a somewhat different character.

On December 22, 1898, he married Ada Hinde Hart of New York, went abroad with his bride, and studied at both Halle and Oxford. Returning to America before the end of 1899, he continued his studies, a partial result of which appeared in "The Composition of Nahum," published in 1901.

With the beginning of his teaching at Andover Theological Seminary in 1902 as Lecturer on the Old Testament, he entered on his real life work. He brought to this work such natural abilities and such careful training that we are not surprised that in 1903 he was appointed Hitchcock Professor of the Hebrew Language and Literature, which title he retained until 1922. When Andover Seminary moved to Cambridge in 1908 he became also Andover Professor of the Hebrew Language and Literature in Harvard University (1908–1922). From 1922 until the time of his death he was Hancock Professor of Hebrew and other Oriental Languages in Harvard University. He was elected to the American Academy January 14, 1914. He was a member of the Society of Biblical Literature and Exegesis, and was elected President of that Society in 1922, his presidential address being "Observations on the Origins of Holy Scripture." Among his other writings are:—The Divine Name in Exodus iii, 14, 1905; The Rhythms of the Ancient Hebrews, 1908; The Passover Papyrus from Elephantine, 1912; Ephod and Ark, 1917; besides contributions to Oriental and Biblical journals.

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[1] Compare the minute prepared by the writer and read by him at the meeting of the Faculty of the Harvard Theological School, February 14, 1930, and printed in The Harvard University Gazette, March 1, 1930.

While Professor Arnold's writings were of such a high type as to give him a place among the foremost Old Testament scholars of his time, probably his greatest work was done with his students, both inside and outside of the classroom. To this he brought a strong personality, a keen mind carefully trained, broad intellectual interests, and an unusual understanding of the niceties of Semitic speech and thought. These characteristics, united with a deeply religious nature, so essential for the understanding and interpretation of a great religious book like the Old Testament, and a warm heart that responded to any worthy appeal, made a deep impression on his students and on his colleagues, who learned to respect him for his rigorous scholarship, to rely on his judgment and insight, and to love him for his personal qualities.

JAMES R. JEWETT.

WILLIAM STURGIS BIGELOW (1850–1926).

Fellow in Class III, Section 4, 1911.

William Sturgis Bigelow, born in Boston April 4th, 1850, died in Boston October 5th, 1926. He was the son of the well known physician, Henry Jacob Bigelow, a founder of the Museum of Fine Arts and a trustee of the institution until his death; and the grandson of Dr. Jacob Bigelow, who was active in founding the Massachusetts Institute of Technology and delivered the address at the opening of its first building. To the scientific interests and public spirit derived from such an ancestry there was added a fine sensitiveness of nature and susceptibility to spiritual values, which he inherited from his mother. the daughter of William Sturgis; she died when he was a boy. Dr. Bigelow was graduated from Harvard College in 1871, and from the Harvard Medical School in 1874. After five years of study abroad, mainly with Louis Pasteur in France, he returned to Boston, to take up the practice of medicine, accepting appointments as Assistant in Surgery at the Harvard Medical School and Out-patient Surgeon at the Massachusetts General Hospital. It is said that Dr. Bigelow, gifted as he was in keenness of mind and deftness of hand, was unfitted by temperament for active practice. He gave up his professional work in 1881 and went to Japan, where he remained till 1888. Here he became deeply interested in Northern Buddhism. Devoting himself to the study of its doctrine, he took the education of a priest and became a regular member of the Tendal sect. One of his few published writings is the Ingersoll Lecture on Buddhism and Immortality, which he delivered at Harvard in 1908.

In Japan Dr. Bigelow came into touch with three Americans who were among the first foreigners to appreciate the significance of Japanese art, Ernest Fenollosa, Edward S. Morse, and Dr. Charles G. Weld. His rare taste and love of the beautiful quickly found satisfaction in the prints, the carvings, the lacquers, and especially the paintings that had come down from the great periods of art in Japan. The time was propitious for the collector. A new spirit, the spirit of Western civilization was abroad; for the moment the Japanese leaders of thought and of taste in great numbers forgot their heritage in enthusiasm for the customs and ideals and achievements of the West; to part with possessions of art which had been cherished in temples and noble families for many generations, no longer seemed a sacrilege. These treasures were offered for sale at prices ridiculously low, since there was no market demand for them. Of this opportunity Dr. Bigelow made free, even lavish use. His delight in Japanese art grew with his purchases, till in a few years he not only became a connoisseur but also gathered an enormous collection which will always remain a tribute to his vision and his taste. This collection was lent and later given to the Museum of Fine Arts. Its value in interpreting Japan to America was recognized by the Japanese government, which in 1909 decorated Dr. Bigelow with the Order of the Rising Sun with the rank of Commander.

Dr. Bigelow's other services to the Museum overshadowed the gift of his collection. On the death of his father in 1891, he was elected to the position of trustee, which his father had held, and for thirty-five years he gave of his best to the institution. For more than half this time he served on the controlling committee, known as the Committee on the Museum. His fellow members came to respect more and more highly his shrewdness, his sound common sense, and his appreciation of art. Not a partisan in spite of strong convictions, of clear-cut purpose in matters of Museum policy, often relieving the tension of argument by a flash of humor, above all things sympathetic and considerate of the views of others, he ever held the esteem as well as the affection of his associates.

If not a connoisseur outside the Oriental field, Dr. Bigelow's interest and pleasure in all phases of art was unlimited. A Greek pottery vase, a Gothic carving, a Persian miniature, or again, a contemporary American painting, appealed to his catholic taste. Music, as well as the visual arts, gave him keen enjoyment. Generous by nature, his interest in young musicians and artists led him to assist real talent unobtrusively, as opportunity came to him, no one knows how often.

Dr. Bigelow had too high a standard of perfection in art and literature to be a writer or an artist himself. I have already said that his published writings were few. Some letters that I received from him I have preserved, though they dealt with questions of the moment, because they were so characteristic of the man. The literary form in a social or business letter, the glimpse of humor, the delicate grace of expression gave lasting value to what otherwise would have had only ephemeral interest. This habit of putting his best self into the little matters of daily life was characteristic of him.

Shy and sensitive by nature but well poised, generous, of warm sympathies, with keen and open mind, it is natural that Dr. Bigelow should have had a few intimate friends rather than very many friends. If evidence were needed of the many-sidedness of his character, it might be found in his friends, leaders in the business world and in the scientific world, leaders in political life like Lodge and Roosevelt, spiritual leaders as different as Phillips Brooks and Okakura-Kakuzo. To these he gave of himself, not only his views of life gathered in the East and in the West, but also a quick openness of mind and of comprehension which was most stimulating in conversation.

We have a tendency in these days to estimate a life in terms of things done. We rate the scientist by his discoveries, the physician by his professional success, the critic by his influence on the taste of his readers. With all his attainments in science, in medicine, and in the appreciation of art, Dr. Bigelow is not to be judged by this American standard of achievement. Perhaps it was the influence of the East that inspired his desire to become deeply acquainted with the world material and spiritual, rather than to leave his mark on it; his willingness to rest satisfied with the contemplation of the truth in science or in art; his effort to explore the possibilities of rich human living. Is it strange if such a character leads us sometimes to question our common standards of judgment? Is it strange if we admire one who understood the uses of leisure, leisure to think, to appreciate, to sympathize, to stimulate, leisure to create his own world in response to his spiritual needs?

Dr. Bigelow will be remembered, not so much for what he did, as for what he was.

ARTHUR FAIRBANKS.

WILLIAM HERBERT BIXBY (1849–1928).

Fellow in Class I, Section 4, 1912.

Abridged from a Memoir prepared by
Herbert Deakyne, Brig.-Gen., U. S. Army, M. Am. Soc. C. E.,
and published in the
Proceedings of the American Society of Civil Engineers,
Part I—May, 1929, pp. 1324–1327.

William Herbert Bixby, the son of Clark Smith and Elizabeth (Clark) Bixby, was born in Charlestown, Mass., on December 27, 1849. He was descended from Colonial stock, his forebears having served in the Colonial and Revolutionary Wars. He attended the public schools of Brookline and Cambridge, Mass., and then entered the Massachusetts Institute of Technology. After one year at the latter institution he was admitted in 1869 to the United States Military Academy at West Point, N. Y., from which he was graduated in 1873, at the head of his class and commissioned a Second Lieutenant in the Corps of Engineers, U. S. Army.

In 1879 he was sent on duty to Europe where he remained until 1882, attending the École Nationale des Ponts et Chaussées of France from which he was graduated with honor in 1881. Returning to the United States, he was placed on duty with the Engineer Battalion at Willets Point, where he remained until 1884. By this time he had reached the grade of Captain in the Corps of Engineers, and from 1884 to 1910, he served as Captain, Major, Lieutenant-Colonel, and Colonel, on river and harbor or lighthouse duty at Wilmington, N. C., Newport, R. I., and Philadelphia, Pa.; at Cincinnati, Ohio, in charge of the Ohio River System; on the Great Lakes at Detroit, Mich., and Chicago, Ill.; and at St. Louis, Mo., as President of the Mississippi River Commission. In 1910, he was appointed Brigadier-General, Chief of Engineers, and served in this capacity until his retirement from active service in 1913. On the entrance of the United States into the World War in 1917, General Bixby was recalled to active duty, and served until 1919 supervising the work of river and harbor improvement on the Mississippi River and its tributaries, in order to release officers on the active list for war service.

General Bixby was as active physically as mentally. As a young man he was an expert skater and, when on duty in France, took occasion during one winter to visit Holland in the hope of acquiring some of the refinements in the art. It developed, however, that his ability as a skater was already so great that he became a teacher rather than a student of the Hollanders. He found time while abroad for mountain climbing and ascended the Matterhorn with two guides. On another occasion he left Zermatt, Switzerland, about noon with one guide and ascended the Breithorn. Returning to the village about noon the next day they met a party starting out to make the ascent. They urged him so strongly to accompany them that he consented and reascended this mountain, getting back to the village about 4 P. M. of the following day, after more than 48 hours of continuous mountain climbing.

He was a man of simple tastes; there was nothing of the martinet about him. He loved the discussion of matters of professional interest and his tremendous fund of knowledge on military and civil engineering, and other scientific subjects, was a source of astonishment to those to whom it was displayed. He was one of the most generous and kind-hearted of men, always thoughtful of the feelings and comfort of others, and most considerate in his dealings with them. His character was unimpeachable, and he leaves a record of service to his country unsullied by the slightest spot of selfish interest.

Deeply interested in scientific progress throughout his active life, General Bixby's interest in science and engineering continued undiminished to the end. In spite of advancing years, he was vigorous both in mind and body until stricken with his last illness when death stopped forever the strivings of his restless intelligence. He died in Washington, D. C., and after a simple service at his home his ashes were placed in the Arlington National Cemetery.

He was married on December 27, 1893, to Mrs. H. M. Jones, of Philadelphia, the widow of Lieut. H. M. Jones, 4th U. S. Artillery. Mrs. Bixby survives him.

E. H. HALL.

MAURICE BLOOMFIELD (1855–1928).

Fellow in Class III, Section 2, 1914.

Maurice Bloomfield was born in Bielitz, Austria, February 23, 1855, and died in San Francisco, California, June 13, 1928. His family moved to this country in his infancy, and he was educated in the public schools of Chicago, in the old University of Chicago (1871–4), in Furman University, Greenville, S. C. (1876–7), in Yale University (1877–8), in the Johns Hopkins University (Ph.D., 1879), and afterwards in the Universities of Leipzig and Berlin. In 1881 he was called to the chair of Sanskrit and Comparative Philology in Johns Hopkins, which he occupied until ill health compelled him to retire in 1926, when he became Professor Emeritus. He received the honorary degrees of LL.D from Princeton in 1906 and from Furman University in 1908, of L.H.D. from the University of Chicago in 1916, and of Doctor *honoris causa* from the University of Padua in 1922. He was elected a Fellow of the American Academy in May 1914. He was an Honorary Member of the Finno-Ugrian Society of Helsingfors, Foreign Member of the Czech Academy of Prague, and corporate member of numerous American and foreign learned societies. He had been President (1910–11) of the American Oriental Society.

He was recognized as one of the leading scholars of the world in both Indology and Indo-European Comparative Philology. To the science of linguistics he made contributions which passed into the realm of the commonplace in his own lifetime. The very term "haplology," as a designation of a now familiar linguistic process, was his invention. Similarly what is called linguistic contamination or blending is now a well-known concept, but much of its meaning is due to his development of the idea.

His originality and profundity are equally evident in his work in Indological studies. He ranks as one of the foremost Vedic scholars the world has produced. His *Vedic Concordance* (1906; *Harvard Oriental Series*, Volume 10) is a work of monumental industry and care, and the idea and plan of it show more than such pedestrian qualities; this book is one of the fundamental tools of Vedic research. At least as much may be said of his *Rigveda Repetitions* (1916; *Harvard Oriental Series*, Volumes 20 and 24). He was a particular specialist in the Atharva Veda, on which he wrote the standard reference-book (*The Atharva Veda*, 1899). Before this he had already published a translation of extensive selections of its most interesting materials (*Hymns of the Atharva-Veda*, 1897; *Sacred Books of the East*, Volume 42). He also, with Professor Garbe of Tübingen, prepared and published a photographic reproduction of the virtually unique manuscript of the text of another school-recension of the Atharva Veda (*The Kashmirian Atharva Veda*, 1901). His most important text-edition was *The Kauçika-Sutra of the Atharva-Veda* (1890). A highly valuable work, both to scholars and to wider circles, was his *Religion of the Veda* (1908). Besides these major *opera*, he contributed to Indic studies by very numerous articles in journals and collective publications, showing in all of them a remarkable combination of deep learning, scholarly imagination, and effective presentation. Special mention should be made of his extensive studies in the stock *motifs* of Hindu fiction, many of which he made the subject of detailed studies which are as fascinating as they are useful and illuminating; through them he developed the idea of an "Encyclopedia of Hindu Fiction-Motifs," which unhappily he never lived to complete, but on the continuation of which some of his pupils are working.

He was no less remarkable as a teacher than as a scholar, and trained a striking number of younger scholars in Indological and linguistic studies. Few American philologists have made so deep an impression upon the scholarly world as he did.

FRANKLIN EDGERTON.

ARCHIBALD CARY COOLIDGE (1866–1928).

Fellow in Class III, Section 3, 1910.

Archibald Cary Coolidge was born in Boston in 1866, the third child of J. Randolph and Julia (Gardner) Coolidge. He was a great-great grandson of Thomas Jefferson. He prepared for Harvard at the Adams Academy in Quincy where he came under the influence of William Everett. Travel, begun under favorable conditions in early boyhood, fired his imagination with a strong desire to know more about foreign countries, and this desire conspired with family tradition and natural aptitude to lead him, while in college, to specialize in History and Government. He graduated *summa cum laude* in 1887. Pursuing the study of history further in France and Germany, he got his Ph.D. with von Holst at Freiburg in 1892. Meanwhile he had entered the diplomatic service; and his interest in history became focused on modern international relations by this experience. In 1890–91 he was Acting-Secretary to the American Legation in St. Petersburg; in 1892 he was private secretary to his uncle, then U. S. Minister to France, and in 1893 he was Secretary to the American Legation in Vienna. He returned to Cambridge in 1893 and from then till the time of his death (January 14, 1928), for six years as Instructor in History (1893–99), for nine years as Assistant Professor (1899–1908), for twenty years as Professor, and for eighteen years as Director of the University Library (1910–28), he served Harvard to the uttermost limit of his capacity. Three times he represented her abroad, in 1906–07 as Lecturer at the University of Paris and other French Universities, in 1908–09 as Delegate to the Pan-American Scientific Congress at Santiago in Chile, and in 1913–14 as Exchange Professor to the University of Berlin. During the last six years of his life (1922–28), besides being Professor of History and Director of the University Library, he was Editor of "*Foreign Affairs*."

He formed the ambition of putting Harvard as a school of History on a par with the great schools of the old world; and, first as a means thereto and then as an end in itself, he undertook to appraise and augment the resources of the University Library. It is largely owing to his efforts that Harvard is able to offer instruction in the history of Latin America, of the Far East, of the Byzantine Empire and of the Slavic countries. His salient characteristics, as they manifested themselves in action to his colleagues in History, are described thus in the Departmental minutes: "He was a man who rose above his prejudices. Inheriting ample means, he felt it to be a national loss, and a reproach to men of wealth and social position, that they left the arduous pursuit of scholarship so largely to others; but he welcomed talent wherever he found it. He was too shrewd and kindly to mistake lack of *savoir faire* for lack of initiative. He gave himself to history; and it was characteristic of him that his gifts to the Department in his lifetime should take permanent form in his bequests. . . . One prejudice he did not rise above—a prejudice for intellectual distinction; but to him this was a thing of many kinds. . . . His attachments were of the heart. He was a man of strong feeling, quick to anger at injustice, profoundly stirred by sympathy. He hated the waste of useless friction and mis-directed strength . . . His mind was essentially political: he knew that he lived in a world of men, not of ideas. What he used to call a decent regard for the opinions of others made him seek counsel as well as give it. Behind the bold unexpectedness of his strokes there was ordinarily much cautious balancing of alternatives; and when he hesitated, it was not from vacillation."

Closely connected with Professor Coolidge's position as a member of the Faculty was his directorship of the University Library during the last eighteen years of his life. To him the Library was a great institution for teaching and research which stood in the closest relations with the daily work of faculty and students, and he labored alike for the fullest development of its collections and the widest opportunities for their use. He directed the details of library administration to an extent that few realized, but he never lost the larger view of the Library's functions and influence. Though much that he did was impersonal and unperceived, it affected none the less profoundly the whole intellectual life of the University. Professor Coolidge's services as Director of the Library have been summarized as follows by the

Library Council: "The first to hold this office, Professor Coolidge gave a creative interpretation to its functions and made it an essential part of the University organization. He kept before the University and its friends a broad and comprehensive idea of the Library and its possibilities, and had the satisfaction of seeing the Harvard Library under his administration reach an assured position among the great libraries of the world. This result was due in large measure to his own wisdom, vision, patient skill, and interest in every side of the Library's welfare. He encouraged equally the acquisition of unique special collections, the prompt and steady purchase of books asked for, and improved facilities for work by members of the University and by visiting scholars. His own unfailing generosity stimulated the generosity of other donors, and his devotion called forth devotion and loyalty on the part of the entire Library staff. Professor Coolidge was an ideal Library Director, and did a unique and enduring work for scholarship and education. His associates in the Library bear him in deep and lasting affection."

Professor Coolidge was a Syndic of the Harvard University Press for the last thirteen years of his life, and he conceived this office positively, as laying on him an obligation to aid in the production of worthy books. While he was more fruitful as an inspirer of the writing of others than as a writer himself, he yet found time to publish certain works of real importance. His Freiburg dissertation on "*Theoretical and Foreign Elements in the Formation of the American Constitution*" was not followed up, as it did not represent his more permanent interests. These came out clearly in 1908 in his volume on "*The United States as a World Power,*" first prepared in the form of lectures at the Sorbonne. Translated into French, German. and Japanese, this met with an instantaneous response in foreign countries, and as time went on its importance was increasingly realized by American readers because of its timely and suggestive presentation of America's place in the world's affairs. In 1917 he published a brief volume on "*The Origins of the Triple Alliance*" (revised edition in 1926), and in 1920–21 he acted as the English editor of "*The Secret Treaties of Austria-Hungary.*" His latest publication, "*Ten Years of War and Peace*" (1927), gathered together the results of his ripest reflections on problems of world politics, many of them by-products of his editorship of "*Foreign*

Affairs." The quality of his writing is evidenced by the comment of President Poincaré on his last published work, an article in the October issue of this journal entitled, "*A Quarter Century of Franco-British Relations:*" "The emphasis is absolutely perfect. No Frenchman or Englishman could possibly have done it. It could only have been written by a thorough master of the subject who could approach it from a completely unprejudiced point of view. It seems indeed the perfect type of historical writing."

In the many years of academic life which followed his brief initiation in diplomacy, he kept in touch with the State Department in his own country and with the leaders in foreign affairs in many countries abroad. He trained distinguished diplomats for our own service, and by repeated travels in Europe, Africa, Asia, and South America, he continued to learn at first hand the problems with which his disciples had to deal. His knowledge of foreign relations grew steadily more intimate and more extensive; he knew not only the history of the nice details of diplomatic negotiations, but he knew also, what diplomatists sometimes ignore, how to appraise the movement of public opinion and to evaluate the great factors of national sentiment, economic motives, and religious enthusiasm. The minds of the diverse breeds of men, from Berbers to Britons, were not alien to him.

During the Great War he was active among the American scholars who were gathering material for use at the Peace Settlement, and the State Department gave him a mission to accompany the fruitless Archangel expedition (1918). As a member of the American staff of the Peace Conference at Paris he was sent for some months to Vienna (1919), where in the most shattered region of Europe he displayed his remarkable capacity for constructive work. In 1921–22, his exceptional knowledge of Russian affairs led to his being attached to the American mission for the relief of starving Russia.

The opportunity, however, for the exercise of a rare combination of wide-ranging and penetrating knowledge with unusual practical sagacity came, in a measure, through the call from the Council on Foreign Relations for the conduct of its journal, "*Foreign Affairs.*" He gave to the journal from its beginning a quality embodying his own insight and catholicity of temper, which assured its influence and reputation. He felt the responsibility of editorship and met its demands with unflagging zeal. Heavy as was the burden, it was carried with apparent ease and with extraordinary competence, so readily were the resources of a strong nature and a trained mind brought to bear upon the new enterprise. It was a happy conjunction, fortunate for the Council on Foreign Relations and not unfruitful for the editor himself; for it enabled him, through "*Foreign Affairs*," to discuss in print the things for which he most cared.

In another period or in another country than his own, Professor Coolidge might have been, it is easy to imagine, a great statesman as minister for foreign affairs. As it was, he put the stamp of statesmanlike greatness on all he did, whether in services abroad, in his library administration, or in preparing scholars and public officials for the needs of the next generation. All these aspects of his work hang together, and they are given deeper unity by his supreme quality of statesmanship.

W. S. Ferguson,
C. H. Haskins.
E. F. Gay,
R. B. Merriman, *Committee.*

Minute for the Records of the Harvard Faculty of Arts and Sciences. Reprinted by permission (with omissions), from The Harvard University Gazette, September 29, 1928.

See also The Harvard Graduates' Magazine, June 1928.

WILLIAM OTIS CROSBY (1850–1925).

Fellow in Class II, Section 1, 1881.

Professor William Otis Crosby was for fifty-four years connected with The Massachusetts Institute of Technology. From its beginning he was a Fellow of the Geological Society of America, in whose Bulletin[1] appeared a memorial prepared by his colleagues A. W. Shimer and W. Lindgren. To this reference should be made for a more detailed account of his work. It remains for this memoir to supplement it and emphasize certain salient points. In this I have had invaluable assistance from his wife and from his classmate, John R. Freeman.

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[1] Bulletin Geological Society of America, Vol. 38, 1926, Pl. 2, pp. 34–45.

And first, as genealogy is but the last chapter of geology, it is well to begin with that. His ancestral line goes back to Timothy Crosby, born in Litchfield, in 1761. This Timothy was a turner by trade, an ingenious Yankee who not only made furniture but wheels, ploughs and other implements. He was William Otis' great grandfather, an industrious man and a strict Presbyterian. His wife was Cornelia Libbey, whose father, an Englishman, was a man of ability and education.

Henry Libbey Crosby, their first child and grandfather of William Otis, was born in Stillwater, N. Y., in 1788. He was a man of high principles and great resourcefulness. He followed farming a part of his life, but for a number of years was connected with Union College, Schenectady, N. Y. as demonstrator in physics. When about forty-five he became a vegetarian partly for his health but also from humanitarian motives. Unlike his father, he was a free-thinker—as unorthodox people were called at that time. He lived to be 89. His wife was Sarah Ann Capron whose grandfather came from England about 1750 and settled in New London, Conn. The family tradition is that he was a surveyor. It is known that he was in the employ of the British government and was much away from home. He remained a Tory while all his family were patriots. His only son, Jeremiah, great-grandfather to William Otis, enlisted in the Continental Army when he was under fifteen, having gained his mother's consent, and came to Boston "to help Gen. Warren drive out the redcoats." His father ordered him home and promised to buy him a commission in the British Army if he would give up his allegiance to the Continentals, but the boy remained firm and was in the Army seven years, taking part in many battles, the first being Bunker Hill. He saw the surrender at Yorktown.

Francis William Crosby, son of Henry Libbey and Sarah Ann Capron and father of William Otis, born Schenectady, N. Y., 1823, was a teacher during his early manhood, later a bridge builder and after the Civil War was engaged in mining. He served four years in the Federal Army with the rank of Captain and Regimental Quartermaster. He marched with Sherman to the sea and then from Savannah north. On that march north he became interested in mining prospects and after the war went to North Carolina as superintendent of a gold mine. This was followed by mining work in Colorado and finally, in 1875, he became superintendent of a gold mine in Venezuela. During the latter part of his long life he travelled much abroad and his letters were mixtures of delightful humor and vivid descriptions. He died in Washington in 1909 at the age of 86. He made extensive collections for the Smithsonian Institution while travelling in Europe.

W. O. Crosby's mother was Hannah Everett Ballard. Through her father, Frederick (Vermont) the line goes back with alternating Johns and Sherebiahs to William Ballard who came from Southwell, England, on the ship "James" in 1635 and settled in Attleboro, Mass. They were men of some importance in their home towns and more than one of them was a pioneer in a new settlement.

Achsah Everett, wife of Frederick Ballard, was the maternal grandmother of William Otis and was a cousin of Edward Everett.

Through different lines the ancestry of both Achsah and Edward goes back to Richard Everett who came from England in 1636 and was the founder of Dedham.

Crosby was born in a log cabin on the banks of the Ohio River, where his father, of deep anti-slavery convictions, had settled down as a school teacher, while by night he maintained a station in the "Underground Railroad" helping fugitive slaves to find their way toward Canada. From his father he derived his own deep convictions about the sacredness of life, and the wrong of needless killing, along with his fondness of acquisition of knowledge and love for the hills. When William Otis was five (in 1855) the family moved to Cincinnati by houseboat and a year or two later they went by river steamers to Iowa, settling in the little town of Toledo. Here Otis, the name he was called by, received his education in the common schools. Cousins who attended the same school with him say that he was usually one of the best in the class and that he was "a wonder in mathematics."

When he was eleven his father went into the army and during the next four years, Otis was the man of the house being the oldest of four children. Times were hard and much hard work fell to his lot even though his health was not robust. But swimming, in which he was proficient, skating, nutting and other simple recreations helped to keep him fairly well. He played endless games of chess with one of his teachers, finding special satisfaction in winning his share.

When sixteen, he went to South Carolina to be with his father in mining, later had two years in the Pension Bureau in Washington as Government clerk and in the spring of 1871 went to Colorado with his father. A journal he kept shows an enthusiastic appreciation of the grand and beautiful in nature and energy in the pursuit of either natural beauty or science. While crossing the plains on this trip, they saw many herds of wild buffalo, not less than 15,000 he estimated, and the bones of many more. He predicted then that the wild buffalo would be exterminated soon.

It was in the early part of this summer while tramping in the Rockies and often spending nights in the open, carried away by the glory of the sunrise from their summits—"worth crossing a continent to see" that exposure and fatigue resulted in a severe cold which laid the foundation of his deafness, a lifelong handicap. For a considerable period during the summer he and his father were working on a smelting furnace of their own invention in Upper Empire and boarding in Lower Empire fourteen hundred feet lower down. Daily they made the climb and descent putting in a long day of hard work between.

Crosby was older than most when he entered Tech. His first knowledge of the Institute and its opportunities came when Professor Richards about 55 years ago organized one of the earliest group excursions of the Institute students in mining engineering to inspect mining operations and visited Georgetown district in Colorado.

Upon Professor Richards making inquiry among local mining men for some young fellow who knew the country to act as their guide and assistant in their excursions, he was told: "Young Crosby is the best you can find. He has tramped everywhere over these hills, has been in all the mines and knows pretty much everything worth while that is going on."

Crosby at that time was about 21 years old, was helping his father operate a small quartz mill near Georgetown and was accustomed to manual labor about a mill and mine. With his father he had previous experience in mining and prospecting in the North Carolina gold fields.

While piloting this party of Professor and students, one of whom was J. R. Freeman, Crosby's ambition to become a student at Tech was aroused, and he quizzed students and instructors about its courses and requirements, even more diligently than they quizzed him about the mines and minerals of the district. On July 27th, the entire party, Otis with them, made the ascent of Gray's Peak 14,500 feet. This was the second ascent of this lofty mountain for him, as he and his father had made the trip a short time before visiting both peaks and spending two nights near the summit. The Technology party camped at a cabin near an old mine part way up, but Otis had decided that he would spend the night on the Summit. When he announced his intention, seven of the students volunteered to join him. They reached the top at 10.30 P. M. and found such a gale of wind that they could barely keep on their feet. They built up a barrier of rocks and lay down in their blankets behind it, but could not sleep. In the morning the fierce wind was still blowing and they watched a gorgeous sunrise by lying prostrate on the rocks. "The sunrise was as grand as the previous night had been terrible, it surpassed anything of the kind I ever witnessed." His companions all declared they would not have missed it if it had cost twice as much. Many meteors fell that night, some of them leaving magnificent trails behind them. The blankets of these eight were covered with frost in the morning. They started down soon after welcoming the remainder of the party on top.

It was not until the middle of November that Otis arrived in Boston and entered the Institute. The following year he spent in Colorado again working with his father, but returned in 1873 and continued through his course without further interruption. During the summer he was with Agassiz at Penikese.

Early in January 1878, he went to Port of Spain, Trinidad, to meet his father who had been very ill with yellow fever at Caratol, Venezuela, and had barely escaped with his life. They spent two months cruising about in those tropical waters or camping on the island of Trinidad.

This was a new and wonderful experience for him. The vegetation, the marine life and the people interested him tremendously. His father lost a brother and a nephew with the fever at Caratal. The trip down was made on a small steamer, the return trip by schooner.

In the spring of '82 an interesting trip to Baracoa, Cuba, was made, the American Consul at that Port having engaged him to prospect for ore. This afforded great opportunities for geological investigation. The trip both ways was by sailing vessel.

Six months in Europe in 1883 when he not only took in all the museums had to offer, but did much field exploration in out of the way places such as the Lipari Islands, gave him experience that was of value to him all his life. When he first came to the Institute of Technology, T. Sterry Hunt was in charge, and he got from him certain erroneous ideas as to the sedimentary origin of felsites, and the possibility of dividing the Pre-cambrian stratigraphically by lithology which show in the nomenclature of his earlier work, but as he told me, a visit to Lipari, from which he gave me a fine specimen of liparite, cleared up his mind on many points, especially on the igneus origin of felsites.

His mind was stored with beautiful poetry so that line of poetry appropriate to the surroundings came to his lips naturally. And in the automobile, or where his deafness marred conversation, he might pass the time by intoning to himself in a low voice lines of poetry.

"The writer," says Freeman, "well remembers him from the first day that he joined the class. His strong face, deeply tanned by exposure, and the earnestness with which he was pursuing knowledge, which some of us were apparently trying to find means to escape, quickly singled him out, and impressed members of the faculty and of the class as out of the ordinary. By the time of graduation, I believe that his classmates would have joined in an expression of belief that he knew more of geology and perhaps more of chemistry than all of the rest of the class combined.

"After graduation, he remained intensely loyal to the class, and interested in all that pertained to the occupations and successes of its members, and in that way your class secretary maintained a considerable degree of intimacy and kept alive the friendship of student days."

"The writer many years ago became impressed with the possibilities of use of a trained geologist in helping a consulting engineer to more complete and accurate knowledge of conditions underground; and when he became a member of the original Metropolitan Water Commission in Boston in 1895, he brought about the appointment of Professor Crosby as consulting geologist to the engineers of the Board. Crosby was set at work studying foundations for the Wachusset Dam, the North Dike and conditions along the route of the aqueduct tunnel. There were some particularly puzzling problems as to the formations at the dam sites and the possibilities of deep leakage through preglacial gorges filled with sand and gravel. Nothing had been said about salary, and when his first account for services was rendered, it came in at the surprisingly small per diem of $10. per day. Upon remonstrating that this was hardly worth the dignity of a Tech professor, his characteristic reply was that he found so many interesting geological problems scattered all along the line that he wanted to spend so much time studying them, that he thought it best to make his per diem small."

Crosby said in later years, that it was Freeman who had dragged him from the professor's chair and workshop into his pleasant contacts with construction engineering. Freeman sought his advice on many problems of dams, reservoirs and foundations and advised others to seek his skill in such investigations; and testifies "that he never found another whose advice was so careful and painstaking in exploring the landscape thoroughly for miles around, before rendering his verdict. While he quickly came to understand the great aid that a geologist could give an engineer, he also found that to get this information in most useful form, it was always better to personally take the geologist into the field and cross question him on the spot, and insist on answers in the language of engineers, lest he write an essay dealing more with historic geology, than with what an engineer should do to be safe.

"Sometimes patience was sorely taxed while waiting for an answer, while the geologist, hammer in hand, climbed the rocks and wandered many miles afield, but when the answer came it always was found based on such thoroughness and with such clear cut reasoning that it carried conviction."

"It was on the result of about two months of most painstaking field work by Crosby that the writer felt justified in recommending the flooding of the Big Meadows District in California, 40 square miles in area, over old lava beds, and with the assurance that it would hold water after a high dam was built. It was Crosby to whom the writer turned when seeking the best dam site on the Medina River in Texas, in a region abounding in giant springs, and trying to make sure before advising expenditure of perhaps a million dollars in a big dam, that the water would not disappear into some underground cavern in the region of the great Barcones fault.

"It was Crosby whom the writer recommended as the most competent man that could be found anywhere for puzzling out questions of the tightness of the reservoir on the Conchos River in Mexico; Crosby to whom the writer turned for tracing the possible leaks in the limestone formation beneath the Hales Bar Dam on the Tennessee River; and again it was Crosby on whom we relied as to the excellence of the foundations afforded by the limestone ledge on which the great dam across the Mississippi River at Keokuk now stands. He traced out the reasons for this remarkable exposure of bed rock at Keokuk, by showing how the Mississippi, ages ago had been pushed out from its original deeper and broader bed to the eastward along a few miles of its course by a great glacier coming down from the northwest, so that it had cut a new and relatively short channel over a broad spur of ledge. It was Crosby on whom we relied for explanation of a most difficult dam site on the Missouri River at Holter, where the great dam now stands, and where two faults appeared to have joined forces immediately underneath the best location for a high dam.

"It was largely on Crosby's studies that the underground conditions for obtaining water supply from the deep gravels in the terminal morraine on Long Island were worked out for the New York Board of Water Supply; and again it was Crosby who first of all worked out the problems of underground formations along the line of the Catskill aqueduct, and who saved his professional fee many times over by the skill with which he pointed out where the fewest diamond drill borings or wash borings, would give the maximum of information at smallest cost.

"The Director of the U. S. Geological Survey told the writer a few years ago that Crosby had become probably the best advisor to be found in the United States upon geological conditions at a dam site presenting difficult foundations.

"His reports were models of clarity and skill in the use of the English languages; and I recall that the late Professor Sedgewick, who himself was one of the best that ever lectured at Tech, told me once of lingering just outside the door of Crosby's lecture room, fascinated by this literary quality.

"Together Crosby and I studied mining prospects in Alaska, in Colorado and on the borders of Death Valley, and thus I came to know Crosby's joy in his work, his kindness of heart, and the keen sense of humor that many did not suspect."

The bibliographic list of the Geological Society memoir does not indicate all of some 109 professional reports, though they all contain interesting geological matter, and an unknown number were printed. When the printing occurred in periodicals as official reports, the Geological Society of America list includes them, but they were also sometimes issued as small pamphlets, e. g. in 1880, one on the Narraguagua Mine, Washington County, Maine, and on the Pembroke Mine, and, in 1896, one on the serpentine marbles of Westfield, Mass.

The outstanding features of his scientific work were these:

He was one of the first geologists, if not the first, to be regularly employed in helping the civil engineer to a more complete and accurate knowledge of underground conditions, such as were encountered in large waterwork propositions, building the largest dry dock in America, and various large dams. This gave him access to and led him to look over large series of borings and thus to studies not only of detailed geology, but of more general interest: such as those showing that much of the clay of till is "rock flour," studies of eskers and other forms of glacial deposits.

His as yet unsurpassed and irreplaceable studies of the rocks around Boston led him to consider jointing as due to earthquake shocks on rocks under strain, and the importance of "keystone faults." His work on the granites around Boston and the Black Hills of Dakota led him to views as to the aqueo-igneous character of pegmatites, intermediate between dikes and veins, which were in advance of his time.

While his deafness hampered his work as a teacher and naturally led him to wait for the other man to speak first, he was most kindly in all relations.

ALFRED C. LANE.

PLINY EARLE GODDARD (1869–1928).

Fellow in Class III, Section 2, 1919.

In the death of Pliny Earle Goddard, which occurred July 13th, 1928, anthropology lost a keen and able investigator and his colleagues and friends a vivid personality, ardent, fearless and loyal.

Born of Quaker parentage in Lewistown, Maine, November 24th, 1869, he spent his early boyhood at Durham where his father was the Friend minister. He attended school first at Vassalboro and then at the Oakwood Seminary at Union Springs, New York, and then entered Earlham College, Indiana where he graduated in 1892. For the next few years he taught school at various places in Indiana and Kansas, having married in 1893 Alice Rockwell of Palmyra, Michigan. Becoming interested in the American Indian, he went in 1897 to the Hoopa Reservation, California, as lay missionary for an inter-denominational organization in Philadelphia. Here his interest in the Indians, already aroused, rapidly deepened, and he set himself the task of making a thorough study of the life and language of this still largely unspoiled tribe. As his work progressed, he resolved if possible to devote his life to ethnological studies. He was entirely without means, without professional training and had a wife and two young children to support. His courage did not desert him, however, and in 1900 his wife and children having returned for a time to her parents, he entered the University of California as a graduate student of linguistics under President Wheeler. In 1901 the Department of Anthropology was organized at the University, and Goddard received an appointment as instructor. His wife and children now rejoined him, ansd with a salary on which he could live without the constant grind of his previous poverty, he continued his studies, received his doctorate in 1904 and two years later was made Assistant Professor. Field work, at first in California and later in the Southwest among tribes related linguistically to the Hupa, among whom he had made his first studies; the preparation and publication of numerous monographs and papers containing the results of his work; and teaching in the University, took up his time.

In 1909 Goddard rather regretfully left Berkeley for the American Museum of Natural History in New York, where he was appointed to an Assistant Curatorship. Within a few years he was promoted to Curator of Ethnology. In his new position his interest turned to specimens and collections, and he became absorbed in rearranging and installing many of the collections under his charge. As an outcome of this work, he prepared and published several admirable handbooks on the Indians of particular regions, such as the Southwest and the Northwest Coast. From 1915 to 1920 Goddard was Editor of the American Anthropologist, and was co-editor and founder with Boas of the International Journal of American Linguistics. From 1915 on he was Lecturer in Anthropology at Columbia University, and at various times held office in all of the various scientific societies and associations in his field.

Goddard's published scientific work lay largely in the Athabascan field, and included studies of the culture, myths and language of many tribes belonging to this widely extended stock. His "Life and Culture of the Hupa," was the first fruit of his years of study with this tribe, and is a brilliant and sympathetic account which at once attracted attention. He followed this by a series of monographs on the Hupa language. His later works dealt with other Athabascan tribes in California, with the Navaho and Apache and with the Sarsi, Chipewyan and Beaver, Athabascan tribes of the Canadian Northwest. His minor papers covered a wide range of topics.

Personally Goddard was a man not easily forgotten. In manner sometimes shy, to his friends he revealed a deep affection, a wit keen and biting, a courage and boundless enthusiasm which endeared him. He felt strongly, spoke fearlessly and so sometimes made enemies. His passing leaves a gap that cannot easily be filled.

ROLAND B. DIXON.

GEORGE WASHINGTON GOETHALS (1858–1928).

Fellow in Class I, Section 4, 1912.

George Washington Goethals was born in Brooklyn, New York, on June 29th, 1858, of Dutch stock from which he inherited a very great tenacity of purpose. His early education was that of the average American boy in a large city. From 1873–1876, he attended the College of the City of New York, after which he was appointed to the U. S. Military Academy at West Point where he graduated with a fine record in 1880. In June of the same year he was appointed second lieutenant of Engineers. From 1885–1887, he was assistant professor of military engineering at West Point. His early work included the construction at the lock and dams of Muscle Shoals on the Tennessee River. During the Spanish War, he was chief of engineers of the U. S. Volunteers and in 1903 he became a member of the general staff. Promotion was so slow that he did not reach the grade of colonel until 1909 at the age of fifty-one, about two years after he had been detailed to Panama. In March, 1915, he was made major general largely on account of work on the Canal and in November, 1916, at the age of sixty, retired voluntarily after having served with distinction in the Great War. It is not necessary here to go into the details of his service, except to say that he always worked with a fearless sense of duty and that efficiency which led Secretary Taft to recommend him to the President for appointment to Panama.

His greatest service to the country was undoubtedly the completion of the Panama Canal begun under two civilian engineers who had followed each other for short terms. It was not the failure of these engineers that gave Goethals his opportunity, but the failure of the system set up by Act of Congress. John Stevens, having established the organization and plan for prosecuting the work of digging and moving dirt, found himself so hedged about by red tape under a commission resident in Washington that he offered his resignation, which was immediately accepted by the Secretary of War. Some years later, General Goethals said that the American people would never do justice to John Stevens in relation to the Canal.

It is said that President Roosevelt determined to send someone to Panama who could not resign. To succeed Stevens in 1907, he selected Lt. Col. G. W. Goethals as an army engineer for service on the Canal and ordered him to Panama. His first year was so disheartening that he was ready to come home. Senator Blackburn, of Kentucky, then civil governor of the Canal Zone showed the President the weakness of an organization which charged a chief engineer with responsibility for the work and permitted him to do nothing without the vote of a commission, resident on the Isthmus. Mr. Roosevelt promptly issued an order placing Goethals in real charge and making the commission his lieutenants. Thus he was able to carry the job through in record time although Roosevelt probably violated an Act of Congress in his order, determined as he was to have the Canal finished, as the American people so evidently desired. In 1914, as the Canal was approaching completion, Mr. Wilson appointed General Goethals governor of the Canal Zone, but the general had no great interest in what he considered more or less of a sinecure. Operation as against construction had no attraction for him.

One of the first positions offered him when he returned to New York was commissioner of police, which he refused because he could not have full authority over the police. He had no patience with responsibility without power and very little faith in popular guidance of executive affairs. His fearless independence was well shown in connection with the Emergency Fleet Corporation in 1917. President Wilson appointed him manager and he accepted with reluctance, serving only three months. There was too much interference by the American Federation of Labor and, besides, he did not believe in one of his principal jobs, the building of a large number of wooden ships.

At the close of 1917, he was appointed acting quartermaster general and became chief of the division of purchase, storage and traffic. After the war was over, he opened an office in New York where as consultant, he undertook the examination of engineering projects. And there he died on January 21st, 1928, in full vigor, one of the great engineers of his country. Sensitive and overmodest, he invariably did his duty without fear.

Ira Nelson Hollis.

GEORGE ANGIER GORDON (1853–1929).

Fellow in Class III, Section 1, 1914.

The story of George Gordon's life is one of the remances in which American history abounds. He was born on January 2, 1853, in Aberdeenshire, Scotland; his father being grieve, or overseer, of the estate of Pitodrie; an efficient farmer, and an upright and rigid Calvinist. His mother, Catherine Hutchinson, was also of sturdy peasant stock, being one of eight children of a farmer-overseer. Thus the boy's early training was in the furrows of the farm and in the elementary discipline of the village school. "Poverty, toil, and hardship," the son later wrote, "bound us together in truest and happiest friendship." In 1871, at the age of eighteen, the son emigrated with his sister, in the steerage, to the United States, and, after a miserable voyage, landed in Quebec, and travelled without food to Boston, where he found occupation, first in a safe-factory, and then as a house-painter and glazier; subsisting as a rule on two meagre meals a day.

His inherited concern for religious association led him to connect himself with a Presbyterian church in South Boston, and its pastor, Rev. Luther H. Angier, perceiving in the youth much promise, promoted his education, encouraged his interest in the ministry, and finally, in 1874, procured his admission to the Bangor Theological Seminary, where evidence of character rather than academic proficiency was accepted as a requirement. In 1877, while still at the Seminary, he was ordained to the ministry at a little village church in Temple, New Hampshire, and a year later applied for admission to Harvard College. He was so lacking in preparatory studies that he could not be enrolled in the entering class, but was, with some reluctance on the part of certain members of the faculty, admitted as a special student. Soon, however, he gave full proof of his ability, and graduated with the class of 1881 with a *magna cum laude* degree and honors in philosophy, winning from Professor W. W. Goodwin the estimate that Gordon was the best student of Plato and Aristotle he had ever had. During his college years he lived with the devoted friends who had in effect adopted him, and later, when their ward was established in pastoral life, Mr. and Mrs. Angier lived with him, and, as a mark of filial gratitude, their name was inserted by him in his own, and he became known as George Angier Gordon.

Immediately after Gordon's graduation he was called to the pastorate of the Second Congregational Church in Greenwich, Connecticut, where for the first time he came into association with prosperous people, and so completely won their regard that a call from the Old South Church in Boston in 1883 was successfully resisted by them. In 1884 the call was renewed and was accepted; though his convictions startled some of his conservative brethren, and his installation council was the scene of an animated contest. From this point, Gordon's career was of continuous and increasing distinction. He not only soon became the representative of evangelical liberalism in Boston, but before long became recognized as the most forceful and convincing preacher in American Protestantism. For forty-five years the Old

South Church was thronged with worshippers, and his retirement, in 1928, seemed an irreparable loss to liberal Christianity.

A long series of published volumes[1] indicates the range and depth of his teaching, and these works were succeeded, in 1925, by a frank and intimate autobiography under the title "My Education and Religion" (1925).

In addition to pastoral duties, many public causes and official obligations claimed Gordon's attention. He was appointed on the first Board of University Preachers at Harvard in 1886–1890, and served again in 1906–1909. He was Ingersoll lecturer at Harvard in 1897; Lyman Beecher lecturer at Yale in 1901, and Preacher at the Summer School of Theology in Mansfield College, Oxford, in 1894. He was four times elected a member of the Board of Overseers of Harvard University, serving from 1897 to 1909, from 1910 to 1916, and from 1925 to the date of his death. He received the honorary degree of D.D from Bowdoin, Yale, Harvard, Columbia, Brown, and Williams; and that of LL.D. from Western Reserve and Boston Universities.

In 1896 he married Miss Susan Huntington Manning, the daughter of Gordon's predecessor as minister of the Old South Church, and she with one daughter, whose intellectual gifts were a joy to her father, survive him. He died in Brookline, Massachusetts, on October 25, 1929, in his seventy-seventh year.

This brief survey is sufficient to indicate the development of Dr. Gordon's career. It was in many aspects quite unlike that of most parish ministers. Instead of being submerged by parochial obligations and visitations, and at the service of every municipal and philanthropic undertaking, Gordon gave his concentrated and continuous devotion to the special function of preaching, in unremitting obedience to the apostolic maxim, "This one thing I do!" He was by habit and inclination a recluse, deliberately dedicating his morning hours to study, and holding himself as a rule inaccessible to the casual visitors who unsparingly invade a minister's working hours with their incidental appeals. When emergencies summoned him from this seclusion he was a rock of defence for the cause which he maintained, and a profound interpreter of personal experience. No one could be more sustaining to sorrow, or commanding in eloquence. His plan of life was, however, definitely designed to promote his special gift, and the intellectual and spiritual preparation for that calling was his daily discipline and joy. The volumes which came in swift succession from his pen were, with few exceptions, by-products of his preaching or material for his work at weekday meetings. His untiring study of philosophy, and especially of Aristotle, gave to his sermons the stability and elevation of a mind in daily converse with great masters. It became clearer with each year that he was concerned with a fundamental change in religious thought, and a new conception of redemption, or what he called, in the volume which he regarded as his best, "Ultimate conceptions of Faith." The professional triumph of his ministry was therefore in reaching such a mastery of majestic truths that he could preach them to his people with vivacity and charm, rather than with the dullness of erudition. No American preacher since Bushnell has so boldly dared to make profound themes the material of parish sermons, and the throng of listeners which filled the Old South Church each Sunday morning was convincing evidence that a preacher of insight and grasp need not fear to instruct his people as well as to exhort them, and to apply serious thinking to homiletical service.

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[1] The Witness to Immortality in Literature, Pnhilosophy, and Life (1893).
The Christ of Today (1895).
Immortality and the New Theodicy (1897) (Ingersoll Lecture).
The New Epoch for Faith (1901).
Ultimate Conceptions of Faith (1903).
Through Man to God (1906).
Religion and Miracle (1909).
Revelation and the Ideal (1913).
Aspects of the Infinite Mystery (1916).
Humanism in New England Theology (1920).
Also many sermons, addresses, and minor publications in pamphlet form.

The personal character of Dr. Gordon was in the highest degree noble and winning. He was a delightful companion to those who were admitted to his intimacy. He had inherited the hardy constitution and the unyielding temperament of his Scotch ancestors, and with these a gift of humor which gave even to controversy a light and playful touch. His literary idol was Robert Burns, who, Gordon jestingly insisted, had more to teach than Shakespeare. He was the most generous and sympathetic of friends, and no less the vigorous and unsparing critic of men who seemed to him mischievous, and of measures which seemed to him ill-advised. No preacher of his generation has done more to justify the calling of the ministry or to illustrate the legitimate function of a Christian Church.

FRANCIS G. PEABODY.

OKAKURA-KAKUZO (1862–1913).

Fellow in Class III, Section 4, 1913.

Okakura-Kakuzo was born at Fukui, the capital of Echizen Province, Japan. His father was a *samurai* who, feeling a deep interest in developing the trade of his country, obtained permission to relinquish his rank and devote himself to mercantile affairs in Tokyo and Yokohama,—a pursuit in which he was able to amass a comfortable fortune. Under such circumstances Okakura-Kakuzo received his early education, and while still very young, entered the Department of Literature in the Imperial University of Tokyo. Here he employed much of his time in the study of English and Chinese, and in 1880, at the age of eighteen, he graduated with the degree of A.M. and with honors in Philosophy and English Literature.

While a student at the University he came into intimate contact with the late Prof. Ernest F. Fenollosa, who was then lecturing there, and under whose stimulating influence Mr. Okakura's attention was, perhaps, first turned to the field of endeavor in which he afterward attained such distinction. From Fenollosa he received many of his early impressions in regard to the arts and ideas of the West, and in return acted as interpreter at Mr. Fenollosa's lectures, accompanied him on tours of research among the temples, and read widely on matters pertaining to art in the literatures of China and Japan.

In 1886 he became Secretary to the Minister of Education, and was put in charge of musical affairs. But later in the same year he accepted an appointment to membership in the Imperial Art Commission which the Japanese government organized and sent abroad to study the fine arts of the Western world. The results of these investigations in Europe and the United States met with just recognition, and on Mr. Okakura's return to Japan, the Government showed its appreciation of his services and attainments by making him Director of the new Imperial Art School at Ueno, Tokyo. This institution repreented the first serious reaction against the lifeless conservatism stills affected by adherents of the Bijitsu Kyokai Art Association and the equally uninspired imitation of Western Art fostered heretofore in the old Government Art School. While recognizing the ideals and realizing the possibilities of ancient Japanese Art, and at the same time aiming at a love and knowledge of the more sympathetic aspects of art in the West, the new school sought to rehabilitate the native arts on a new basis whose corner-stone should be "Life True to Self." For the carrying out of such a project Mr. Okakura possessed unusual qualifications, equipped as he was with a profound and reverent understanding of Asiatic art, and a considerable familiarity with the best that Europe had produced. But rapid political changes in Japan brought in their train renewed insistance on the adoption of Western ideas in every branch of activity, and when, in 1897, it became clear that European methods were to be given an ever-increasing prominence in the curriculum of the new Art School, Mr. Okakura felt obliged to resign his Directorship. Six months later he had gathered about him thirty-nine of the leading artists of the time,—including such painters as Hashimoto, Gaho, Kanzan, and Taikan,—with whose collaboration he organized and opened the Nippon Bijitsu-in, or Hall of Fine Arts, at Yanaka, in the suburbs of Tokyo. Here a fresh effort was made to assimilate all that is best in Western Art with the loftiest native traditions, so as to extend, without impairing, the vigor of national inspiration. The major and minor arts in all their forms were practiced and exhibited, and the success which attended this undertaking was soon felt in the strong influence which it exerted.

Prior to and during these activities, however, Mr. Okakura was profoundly interested in the researches which the Government had been led to make with a view to seeking out and registering the art treasures which then, much more than now, were scattered among the temples and monasteries of Japan. The first tentative steps in this direction were those taken by Professor Fenollosa during the early eighties. But the work was soon more thoroughly organized, accurate registration was begun, and to the prosecution of this important task Mr. Okakura devoted much of his energy. As time went on, stress was laid upon the increasing rapidity with which the great paintings and sculptures, accumulated through the centuries by the religious sects, were passing into the possession of collectors all over the world, and public opinion finally became sufficiently aroused to enable Mr. Okakura to secure the enactment of legislation which declared all such works of art to be National Treasures, prohibited their sale or removal, and established as their custodians a body of artists and scholars known as the Imperial Archæological Commission. With the work of this Commission Mr. Okakura was associated in an active or, later, advisory capacity until his death; and it is to him more than to any other man that Japan owes the preservation within her own borders of the painted and sculptured masterpieces of art which will always rank among the greatest achievements of the human race.

The results of Mr. Okakura's visits to China and India, where he made exhaustive studies, are brilliantly set forth in his book, "The Ideals of the East" (1903), explaining his important and now generally accepted analysis of the movements of thought and art throughout Asia. Other books by him, dealing with similar subjects, are "The Awakening of Japan" (1904) and "The Book of Tea" (1906). But apart from these volumes his literary activity was considerable. Some of his writings appeared in periodicals, notably in the earlier numbers of *Kokkwa*, and others are more permanently preserved in the art section of Brinckley's *Japan* and in *Japanese Temples and Their Treasures*, a government publication, of which Mr. Okakura was the editor and, to a great extent, the author. He also contributed to the publication of the "Histoire de l'Art du Japon," a monumental work compiled for the Japanese Commissioners to the Paris Exposition in 1910, and, in addition, he delivered many lectures—some of which have been published—before various learned societies and at the Imperial University of Tokyo, where in 1909, he was appointed Lecturer on Æsthetics.

His connection with The Boston Museum of Fine Arts first as Advisor and later as Curator of the Department of Chinese and Japanese Art, began in 1906. His first care was to begin the arrangement and classification of the vast collections of the Department with a view to cataloguing them. The mere mechanical labor was far greater than any one man could attend to, and he secured the assistance of competent experts from Japan to classify the lacquers and metal work, while he himself undertook the examination and cataloguing of paintings and sculptures. It was a matter of great interest to see how rapidly the systematic study of art in Japan along the lines of Western research had altered the standards of judgment in twenty years, especially in the matter of the conventional attributions, many of which were completely reversed. Pictures supposed to be originals were in some cases discarded, while their places were taken by others to which, twenty years before, relatively little importance had been assigned. This catalogue, which was finished comparatively lately, was made out in such a form that, after the usual details about the size, character, and attribution of each picture, a blank space is left for comment by any qualified expert who may be visiting the Museum. It remains a model for all time of what a catalogue should be.

Mr. Okakura's work was untiring, incessant and extended in many directions. He lectured much at the Museum and on many subjects.

He had the simplicity of genius. He was, perhaps, the greatest scholar and most original writer of modern times on Oriental Art. But this was far from being his only interest. His mind was encyclopædic. It seemed impossible to ask him a question, not only in regard to art and poetry, but in regard to history, or philosophy, or religion, in Japan, China, or India, which he could not answer from first knowledge, not only as a student, but as a traveler. He had been around the world repeatedly. He had been to China many times and visited pretty much every place noted in its religious, artistic, or political history. He spent nearly two years in India, with which he was equally familiar, notably in respect to religion, art, and philosophy. His grasp of our Western literature and fine arts was extraordinary. His appreciation was keen and his judgment sound and extremely discriminating. He liked Raphael and disliked Rubens. Of the Cubist pictures he said, "I stretch out my mind toward them; I touch nothing." He was past master in those refinements of Japanese civilization which are part of the education of a gentleman, such as writing poetry and arranging flowers, in music, in the formal tea ceremony, fencing, and jujitsu. He was an "Admirable Crichton" in his way, with a grasp of the best intellectual products of the highest civilizations on both sides of the world, which completely invalidated Kipling's famous line:

> "Oh, East is East, and West is West, and never the twain shall meet."

They met in Okakura-Kakuzo.

William Sturgis Bigelow.
John E. Lodge.

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THEODORE WILLIAM RICHARDS (1868–1928).

Fellow in Class I, Section 3, 1891.

Theodore William Richards was born in Germantown, Pennsylvania, on January 31, 1868. Of his father William Troost Richards (1833–1905) he has written: "A rare enthusiasm for the beauty of nature; remarkable technical facility with pencil and brush as an artist; strong visual memory and pictorial imagination. A very steady, straightforward, honorable, wise, generous man." Of his mother, Anna Matlack Richards (1835–1900), "Devoted to literature; unusual wit and originality; deep interest in religious and moral problems; an author of several books. A brilliantly intelligent, highly conscientious, high minded woman, who thought too deeply concerning the injustices and inequalities of human fate to be very happy."

The doubtful success of the local schools with the older children led his mother to undertake his entire primary and secondary education. When thirteen he was given a small box of chemicals and apparatus, in which he became deeply absorbed, and soon after he was invited to attend some of Wormley's lectures at the University of Pennsylvania. In 1882, when less than fifteen years of age, he became a sophomore at Haverford College—without having previously attended school—and began the formal study of chemistry under Lyman B. Hall. After graduation in 1885 he entered the senior class in Harvard College—its youngest member—and was awarded the bachelor's degree *summa cum laude* at the Commencement following. At Harvard he studied chemistry intensively under J. P. Cooke, H. B. Hill and C. L. Jackson, beginning while a senior his first research "On the constancy in the heat produced by the reaction of argentic nitrate on solutions of metallic chlorides" which appeared in the Proceedings of this Academy in 1886. After graduation he investigated, in Cooke's laboratory, the relative atomic weights of oxygen and hydrogen and in addition those of copper and silver. The degrees of A.M and Ph.D. followed in 1888 after which he studied with Jannasch and with Victor Meyer at Göttingen, with Krüss at Munich, and with Hempel at Dresden. Before returning to Harvard in 1889 he visited many European laboratories, and became acquainted with most of the eminent chemists of that time.

In 1891 he was made Fellow of this Academy, which was thus the first of many learned societies to recognize his talents. He was its President 1919–1921, and published a large number of papers in its Proceedings.

In 1895 occurred the death of Cooke, whose "Chemical Physics" had done so much to stimulate in America the study of the new physical chemistry. The Corporation of the University at once voted Richards leave of absence for the second semester to study with Ostwald in Leipzig and with Nernst in Göttingen, Upon his return he succeeded Cooke in the exposition of this subject, and consistently applied its principles to the solution of his own experimental problems.

In 1896 he was married to Miss Miriam Stuart Thayer, daughter of the distinguished Biblical scholar Dr. Joseph Henry Thayer. Three children were born to them:—Grace Thayer Richards (Mrs. James B. Conant), William Theodore Richards (now assistant professor of chemistry at Princeton) and Greenough Thayer Richards, an architect. The delightful hospitality of their home at 15 Follen Street, Cambridge will not be forgotten by any who were privileged to share it.

In 1901 Richards was called to a full professorship of research at the University of Göttingen, for an American chemist an honor unprecedented. He accepted instead a similar promotion at Harvard, and at the same time the heavy burden of teaching which he had carried was materially lightened. But he never would surrender "Chemistry 8," in which modern chemical theory was approached in elementary fashion through a study of its history, or "Chemistry 6," which developed physical chemistry from a most clear and penetrating analysis of its fundamental concepts and relations.

In the spring of 1907 he was visiting (or exchange) professor at the

University of Berlin, where he lectured on exact quantitative procedure, and initiated a number of advanced workers into his laboratory methods.

On June 14, 1911, he delivered in London the Faraday Lecture of the Chemical Society on "The Fundamental Properties of the Elements" and received the Faraday Medal. He had always been deeply impressed by the personality and the achievements of the great Englishman, a large picture of whom was for many years displayed in his office. This occasion therefore brought him unique satisfaction.

Over half of Richards' scientific life had been spent in Boylston Hall, a building originally constructed for miscellaneous purposes and peculiarly unsuitable for exact chemical work. Crowds of students, dust, fumes, cramped quarters, and vibration had caused him incalculable worry and loss of time. But in 1912, graduates and friends of the University provided and endowed a modern research laboratory for the exclusive use of Richards and his collaborators. Bearing the name of Wolcott Gibbs, pioneer in American chemistry, this building embodies in every detail the experience and the foresight of its first Director. Fifteen years later he co-operated in designing the new Mallinckrodt and Converse laboratories at Harvard, and lived to see them far advanced toward completion.

The year 1913 was marked by his election to the presidency of the American Chemical Society. A year later he received notification of award of the Nobel Prize in Chemistry for 1915, the first American chemist to be so honored. His Nobel Lecture on Atomic Weights, delayed by the Great War, was published in 1921. Of the many other honors conferred upon him should be mentioned honorary degrees from Berlin, Christiania, Clark, Harvard, Haverford, Manchester, Oslo, Oxford, Pennsylvania, Pittsburgh, Prague, and Princeton; the Davy, Franklin, Willard Gibbs, LeBlanc, Lavoisier, and Rumford medals; membership in twelve of the most important learned societies of the world; decorations with the Cross of an Officer of the Legion of Honor. In 1925, Thomas W. Lamont established at Harvard the Theodore William Richards Professorship in memory of his brother Hammond, Richards' classmate and friend.

Over three hundred papers were published by Richards individually or in collaboration with students or assistants. These papers were indeed extraordinary in originality, scope, thoroughness and skill in execution. Not second in importance to their outcome were the ingenious devices and the refinements in method incident to them.

His early fame rested mainly upon his revisions of the atomic weights, the possible implications of which always fascinated his imagination. His apparatus and technique set the standards for subsequent work, and his values have been universally adopted.

The research with J. P. Cooke on oxygen and hydrogen, mentioned above, offered the first proof that the ratio of their atomic weights is distinctly less than 16:1, and gave a result for hydrogen differing by only four parts in ten thousand from the present accepted value. Observations made in the course of the above work led to an investigation of the atomic weight of copper, which continued until 1891, and which showed that oxides prepared by ignition of nitrates always retained gases. The elimination of this error led to a better atomic weight for copper, and pointed the way to a revision of other atomic weights as well.

Barium chloride and barium bromide were next analyzed. Complete expulsion of water without decomposing the salts, and careful corrections for the solubility of silver chloride were the chief improvements which resulted in a greatly improved atomic weight for barium. Strontium, magnesium, zinc, nickel, cobalt, iron, uranium, calcium and cesium were then studied in succession, by following methods similar to those previously followed.

Richards' analyses of strontium chloride and bromide respectively led to divergent results for the atomic weight of strontium. Could the atomic weights of chlorine and of bromine as determined by the great Belgian chemist Stas have been in error? The investigation of sodium chloride and bromide, in 1904, showed that Stas' value for bromine was correct, but that his figure for sodium was distinctly too high and that for chlorine considerably too low. In the course of this work the errors into which Stas had fallen were revealed and eliminated. Inevitably these researches raised questions regarding the accuracy of other atomic weights in use at that time. Potassium, sulfur and nitrogen were attacked, the latter in part at Berlin during Richards' exchange professorship there. In the synthesis of silver nitrate new evidence was added to the usual criteria of the purity of the final product of the experiments by completely decomposing it and demonstrating its freedom from water. The extreme variation between the results of six successive experiments was less than one thousandth of a percent,—an unexampled degree of concordance. Lithium also received attention, and Stas' result was shown to be a whole percent too high, "because all the defects in his process accumulated on the head of this the lightest of all the metals."

Richards has emphasized that the chemical difficulties in atomic weight work greatly exceed the physical ones,—weighing for instance. Therefore a relatively small quantity of material of undoubted purity properly handled will give a better result than the huge quantities of less pure material taken for analysis by Stas. The control of the solubility of precipitates (and of the walls of containing vessels), elimination of the occlusion of foreign substances by solids, and the complete expulsion of water without hydrolysis from all substances that must be weighed, are the chief requisites for success. These objects were attained with the help of the nephelometer, a device for estimating the quantity of suspended precipitate by means of the light reflected from it, by consistent use of the centrifuge after crystallizations, and by a bottling device which made it possible to enclose and weigh a pure anhydrous compound without an instant's exposure to the outside air.

In 1914, Fajans sent his pupil Max Lembert to Richards with a sample of "lead" of radioactive origin to find whether the end product of disintegration of the uranium-radium series did indeed have an atomic weight of 206, i. e. a unit less than that of ordinary lead. This sample also others from uranium and thorium minerals were investigated, and atomic weights ranging from 206.40 to 206.82 resulted. The deficiency thus attained 0.75 unit. This rough experimental verification of the theory of isotopes attracted wide attention and greatly stimulated activity in this type of research. Further work in Richards' laboratory lowered the "record" on uranium lead to 206.07, which would be lowered to 206.02 if a correction were made for the thorium lead doubtless present. Of equal interest was the proof that the physical properties agreed within a small limit of error with those of common lead in all respects except those fixed by mass. Thus *molal* solubility was identical, as well as refractivity, melting point and thermoelectric height. Attempts to effect partial separation of isotopes of lead by fractional crystallization or by fractional distillation of lead tetraphenyl yielded negative results.

The atomic weight of carbon was attacked by converting sodium carbonate into sodium bromide and this into silver bromide, thus obtaining the molecular weight of sodium carbonate in terms of silver. Also sodium carbonate was converted into sodium sulfate and the molecular weight of the latter referred to silver through the molecular weight of sodium carbonate. Richards spoke of these researches as confirming, by cross-reference, many varied methods and results. Revision of aluminum was of interest as quite definitely placing aluminum slightly below 27. Gallium determined with elaborate care (first revision since discovery, 1878) yielded 69.716, widely departing from an integral value.

The accurate determination of atomic weight now enjoys added importance by indicating (1) whether given elements are probably simple or complex (2) the packing effect in simple elements (3) whether the relative proportions of isotopes determined by Aston's mass spectograph predict a reasonable average atomic weight (4) whether a given atomic disintegration scheme is plausible.

Richards' second major interest was centered in the volume occupied by matter. His early suspicion that the quantity "b" in the equation of van der Waals was variable led to his hypothesis of the compressible atom, slow of general acceptation, but today an integral part of physical and chemical theory. The striking contractions which elements suffer upon union to form compounds he properly attributed to the compression and deformation of atoms by gigantic cohesive and chemical affinities. In developing his theory he measured with precision the compressibilities of about forty elements, and showed the former to be a function of atomic volume. As he expected, those elements which were already most compressed under increased external pressures. He not only demonstrated, as Davy had indeed foreshadowed, that the contractions incident to compound formation were nearly proportional to the energy changes of the corresponding reactions, but also proved that the proportionality is much more exact if due allowance is made for the individual compressibilities. In another series of papers he furnished new and exact data on densities, surface tension and heats of combustion, and correlated these properties as well as melting points, boiling points and latent heats with compressibilities, interpreting the regularities in terms of cohesive and chemical affinities and emphasizing in the case of the elements, the periodic relationships. These undertakings were in part responsible for his brilliant investigations in the field of thermochemistry, which we must now consider.

Richards' very first paper as previously stated, dealt with thermochemistry. He resumed publication in this field in 1905, describing a novel and precise method of determining specific heats and reaction heats of liquids. The same year saw the beginnings of adiabatic calorimetry, which was later developed in elaborate detail, including an automatic method (synthermal regulator) for keeping the temperature of outside bath exactly equal to that of calorimeter over long periods, thus making possible exact determinations of energy changes in slow reactions. The specific heats of elements at low temperature, the adiabatic determination of heats of solution of metals in acids, of heats of combustion of organic compounds, heats of vaporization, specific heats and heats of neutralization as well as heats of dilution of solutions of acids, bases and salts, provided thermochemistry with a wealth of accurate data previously lacking and furnished the basis for new thermodynamic generalizations. Just as important as these data were the improved apparatus, the tricks of manipulation, and the demonstration of sources of error hitherto unrecognized or hopefully neglected. Noteworthy was the elaborate calculation involving carefully determined heats of dilution by which Julius Thomsen's errors were demonstrated, and the proper values of the heats of solution of metals in acids as dilute as $HCl.200\ H_2O$ were figured from data obtained in stronger acids.

Seldom has such mastery of the use of the mercury thermometer been attained as in Richards' laboratory. In 1898, recognizing the difficulties which chemists must encounter in this difficult art, he began a series of determinations of transition temperatures of hydrated salts, first sodium sulfate, later sodium bromide, manganous chloride, sodium chromate, and strontium chloride, to serve as reference points. From 1902 on, these were referred to the international standard. For calibrations below zero he determined the equilibrium temperatures between pure ice and hydrochloric acid solutions of various concentrations. The method of floating equilibrium consisted in determining the temperatures at which different analyzed solutions of a given salt would attain exactly the same density as a given float, and the graph depicting such data serves for later calibration of thermometers,—if the float retains its average density unaltered or if a minimal change in density can be evaluated by extrapolation. Reversing the method, densities can be determined in terms of temperatures. The solubility curve of sodium sulfate also was applied to calibration of thermometers as well as a calometric method using electrical energy for dividing up temperature intervals. Of all these methods, the transition temperature of sodium sulfate, whose unusual crystal form is conducive to easy and certain purification, will perhaps remain the most valuable.

In Richards' later calorimetric work, thermoelements played a prominent part, and their manipulation and vagaries were studied with the same thoroughness that marked his use of mercurial thermometers.

Richards' electrochemical work had far-reaching consequences. In 1902, after a study of a series of galvanic cells of the Daniell type, he pointed out and correctly explained the relation between the sign (and magnitude) of the difference between free and total energy change in a given chemical reaction and the sign (and magnitude) of the heat capacity changes involved in the same reaction. He showed that free and total energy should be identical when no heat capacity changes occur, and that in other cases the two should approach each other with falling temperatures, and become equal at the absolute zero. Upon these relations clearly outlined by Richards, Nernst later based his "third law of thermodynamics." Experiments about the same time on Faraday's Law showed it to be extremely exact and generally applicable. Richards studied at length cells having as electrodes amalgams of a given metal in different concentrations. As these became exceedingly dilute, the electromotive force approached as a limit that predicted by the gas law, while the deviations measured at higher concentrations were shown to illustrate other thermodynamic relations. Among single potentials revised should be mentioned that of iron, and the influence upon it of occluded hydrogen, including also the effect of a magnetic field.

Other important studies all worthy of extended discussion, treated cuprammonium salts, reaction mechanism, complex ion formation, a kinetoscope for the study of crystal growth by successive instaneous photographs; the relation between the taste of acids and their degree of dissociation, improved methods for vapor-density determination and metallography.

Richards' almost life-long interest in cohesion and its effect upon volume culminated in efforts to evaluate the internal pressures of solids. An analysis of his reasoning from his data, though of great interest, would be too lengthy, so that it must suffice to give his final expression:

$$p + \pi_0\left(\frac{V_0}{V}\right)_T^m = (\pi_\rho)_0\left(\frac{V_0}{V}\right)_T^n + P$$

Here p represents external pressure, and V the volume, π is the internal or intrinsic cohesive pressure (i. e. inherent in the material) π_ρ the internal or intrinsic distending pressure and P the internal thermal pressure. Of the exponents m must be smaller than n. The subscript zero refers to the condition when $p = 0$, and T, of course, indicates the temperature of the system in equilibrium. Thus the sum of external and cohesive pressures balances the sum of distending and thermal pressures. Richards calculated the intrinsic cohesive pressures at 200°C of nineteen isotropic elements, and obtained values ranging from 8000 megabars in the case of cesium to 1,020,000 in the case of tungsten.

The desire to impart to others his skill, his ideals and his love for research stood on a par with his enthusiasm for his own projects. Not less than eighty-eight names of his research students or more advanced collaborators appear on his published papers, and few indeed worked under his direction without turning out publishable results. An unusually large proportion of his students have reached positions of importance in research, teaching and industry. They, and their pupils in turn, have greatly extended the range of Richards' influence upon the development of chemistry in America and even in other countries.

Richards always distrusted hypothesis to the extent that clean-cut experimental verification, in the given case, appeared to him remote, so that his published papers give little idea of the constant activity of his vivid scientific imagination. He maintained, besides, that extended mathematical treatment of the complexities of chemical systems and chemical changes is much more likely to lead the experimenter astray than if applied to the more simple phenomena of physics; so he usually contented himself with the mere statement of data, and inferences obviously valid. His experimental work was never subjected to correction except in the matter of a small over-estimation of the occlusions in the silver coulometer. He was conservative in his own claims regarding priority, and generous in the acknowledgment of the deserts of others. In the light of these facts, we can readily explain the freedom of his record from the polemics which have embittered and hampered so many eminent scientists. His energies were thus conserved for his ever-broadening program of activity in research. Not everybody realized that it was only his devotion to this which often prompted his courteous declination of requests to participate in conventions, meetings, committee work, consultation work, editorial work, and compilations, which choke the careers of so many promising scientific men. His oft-repeated words "Every hour is precious" voiced a deep conviction which consistently guided his decisions in such matters.

Any attempt to characterize briefly so many sided a man must fall short of adequacy, but, at the least, tribute must be paid to his amazing experimental skill and critical judgment of experimental data; his unsurpassed standards of scientific integrity, no matter what the price in time, energy, outlay, expectation; his deep insight into the underlying significance of physical and chemical phenomena and the clarity with which he explained them; his enthusiasm, patience, and good humor, which never failed in trying circumstances; his keen enjoyment of the finest in art, music, and literature; his solid administrative ability and sound business sense; his genuine interest in the scientific and personal problems of those who sought his help, even to the humblest freshman; and the unsparing expenditure of self in every duty up to the very end of his life. He has won an enduring place in science and the undying esteem and affection of those who labored with him.

GEORGE SHANNON FORBES.

ADDISON EMERY VERRILL (1839–1926).

Fellow in Class II, Section 3, 1887.

In 1864, when Yale decided to introduce the science of zoology into her curriculum, she naturally looked to Louis Agassiz to supply a man with the training needed to establish such a department, and it was her good fortune that his choice fell upon a promising young assistant of his, Addison Emery Verrill.

A native of Maine, Verrill had been enthusiastic in his pursuit of natural history since early boyhood, and by systematic collecting and study of both plants and animals had already laid the foundation for his life work in taxonomy. He arrived at Harvard in the spring of 1859, the year following was made assistant to Agassiz in the Museum of Comparative Zoology, and received his B.S. degree in 1862.

His first work at Yale was the development of a zoological museum out of the old "Natural History Cabinet," a task he continued with such diligence that when he relinquished it in 1910 the Yale series of marine invertebrates was one of the best in American museums. The great bulk of these accessions came as the result of his connection with the United States Fish Commission, which entrusted to him the supervision of the material assembled during a comprehensive survey of the coastal waters of New England made between the years 1871 and 1887.

This constant stream of material passing through Verrill's hands brought to light many forms new to science, and these he described from time to time, thus becoming the author of a large number of new species. In fact, the new forms that he described in the course of his life are said to total over a thousand. When the dredging was completed, it was his plan to monograph the various groups, but he was able to carry this out for only the nemerteans and planarians.

In addition to this work on the New England waters, Verrill became interested in various other faunal regions, and visited them personally for the purpose of studying their life. In 1861 he made a famous trip to Anticosti Island and Labrador with Shaler, Hyatt, and Upham Treat, the four dividing amongst them the duties of navigation as well as those of scientific investigation, and the material thus gathered was later described in part by Verrill. Almost forty years later he turned his attention southward to the Bermudas, which he described not only faunally, but physiographically, geologically, and historically, in a monograph of 548 pages (1902). At the age of eighty-five, says Professor W. R. Coe, his successor and biographer, "he entered upon the exploration of the marine fauna of the island of Kauai, in the Hawaiian Island group, with all the enthusiasm he had felt in his college days at Anticosti."

Due to unusual physical strength and endurance, permitting him to work far longer hours than is possible for most men, Verrill's record of accomplishment was prodigious, his published papers numbering more than 350. Of the various marine invertebrates, he paid particular attention to the coelenterates and echinoderms, producing upward of fifty papers or monographs on each of these groups, among which might be mentioned especially his monograph on the Alcyonaria of the Blake Expedition (now in press) and his two-volume work on the shallow-water starfishes of the North Pacific. Deserving mention also as perhaps his most widely known work is his "Report on the Invertebrate Animals of Vineyard Sound and Adjacent Waters" (1872), which was for more than thirty years the classic reference book for studies of that region. In these works, as in others, he had the valuable assistance of his brother-in-law, Professor Sidney I. Smith, professor of comparative anatomy at Yale from 1875 to 1906. Of great reference value also are the zoological definitions and their illustrations in Webster's International Dictionary, which came from Verrill's pen.

In brief, again to quote Professor Coe: "With the exception of the protozoa, the taxonomy of every one of the invertebrate phyla shows the effect of Verrill's labors. In some, the general scheme of classification was modified, in others new genera and species were added. In all, he exhibited what seems to have been a natural intuition as to the significance of morphological characters which amounted almost to genius. . . There seems little doubt that future generations will accord him recognition as one of America's greatest systematic zoologists and one of the most productive of our zoological pioneers" (Amer. Jour. Sci. (5), vol. 13, 1927, p. 386).

CHARLES SCHUCHERT.

ALLYN ABBOTT YOUNG (1876–1929).

Fellow in Class III, Section 3, 1921.

Allyn Abbott Young was born at Kenton, Ohio, September 19, 1876. He was of New England stock, his forbears English on both sides. The family was intellectual; the father, a brother, and a sister, were teachers of high quality. His undergraduate work was done at Hiram College, Ohio, where he graduated in 1894. After taking his Ph.D. degree at Wisconsin in 1902, he entered on a remarkably varied academic career, at Western Reserve University, Dartmouth College, the University of Wisconsin, Stanford University, Washington University (St. Louis), Cornell University, Harvard University, and the London School of Economics. At each institution he left an abiding mark, and from each he was drawn to the next not only by the prospect of higher position and more congenial work, but by a certain spirit of adventure. His was a wide-roving disposition; the trait showed itself not only in the many shifts of his carreer but in the range of his scholarly work. It was this trait which explains the very last move, which ended so tragically. He had cast his lot with Harvard University for good—of this he and his associates had no question—when he was asked in 1927 to accept the professorship of Political Economy at the University of London. Brought into close personal touch with European statesmen and economists in the course of his service on various committees and organizations dealing with the post-war problems in economics and politics, he had made on them the impression of signal competence which never failed. Hence the London invitation. It proved tempting, not only because of the attraction which a new sphere of work always had for him, but because of a natural pride in being the first American economist invited to a high academic post in European countries. After repeated solicitation, and much searching of heart, he finally accepted a three year appointment, the Harvard Corporation generously giving leave of absence for this unusually long period. His English friends made no secret of their wish to retain him permanently; and in the course of the academic year 1928–1929 he was also tendered a professorship at the University of Chicago on terms highly attractive both as to salary and duties. But he never had an expectation of remaining at London after the three year period; his heart was at Harvard, and he had made up his mind to return there.

All these expectations were confounded by his sudden death. He had been in the United States shortly before, in December–January, apparently in full vigor; and a few days before the end had taken the lead in a discussion of the reparations question at a dinner-meeting of the historic Political Economy Club of London. An attack of influenza developed into virulent pneumonia and he died after a few days of illness on March 6th, 1929.

Young's attainments were extraordinarily wide. Within the range of economics there was hardly a field in which he was not eminently competent. From the most refined theoretical niceties to the most complicated realistic stiuations, his grasp was secure and his judgment keen. He was a mathematician of the first order; a statistician attentive to the concrete phenomena underlying the bare figures as well as to the most exacting requirements of refined technique; conversant with economic history; alive to the remarkable and often unique phenomena which have unrolled themselves before our eyes during these first three decades of the twentieth century; above all, a master of the principles of economics, steeped in the great literature of the subject, its method, its relation to other disciplines. With this complete grasp of his chosen subject, he combined an interest and comprehension in a wide range of others,—not only history and politics, but natural science, philosophy, and literature. He had picked up for himself an abundant linguistic equipment. Not least, he had a deep warm interest in music, was no mean performer on the organ, and at one stage in his career supplemented a slender income by playing that instrument. He knew all the great composers and their works, enjoyed and judged a great interpretation. Here, as in his intellectual outlook, he valued the old without belittling the new.

Young left behind him no large body of written work. A great number of reviews and brief notes, and some elaborate papers, on a surprising variety of subjects, appeared in periodicals and in the transactions of societies. Some of the more notable of these were gathered in a volume, "Economic Problems New and Old," published in 1927. He had in preparation a book on money and credit—one of the many fields in which he had worked intensively—and it is hoped that enough of this is in definitive form to justify publication. He had planned also to write a book on the fundamentals of economic theory. No one was better qualified for this ambitious task. Everything that he wrote bore the marks of independent thought, keen discrimination, ripe judgment, a background of much more than could be set forth at the moment. And everything bore the marks of the literary craftsman. He had the gift of rounded and dignified utterance; not so pellucid as to save the need of attention and reflection, always allusive, but always urbane, and of unmistakable intellectual distinction. Perhaps he was at his best in papers and addresses surveying some broad subject; such as the presidential address before the American Economic Association on "Economics and War," a paper at the University of Virginia on "The Trend of Economics," the inaugural lecture at the University of London on "English Political Economy," and the presidential address before Section F of the British Association on "Increasing Returns and Economic Progress."

Tall and alert, handsome in feature, impressive in bearing, mature and poised, he made his mark whatever the company. And with distinction he combined unfailing sympathy and responsiveness. No one ever went to him, whether a troubled colleague or a timid novice, without helpful response. He was perhaps at his best with advanced students who were probing their way into the core of some intricate problem.

To all, young and old, he gave of his time and strength without stint. Probably he gave too much; more could have been achieved for the world and for himself if he had been firmer in saying no. One of the things that tempted him to the London adventure was the prospect (which he thought he saw) of less distraction and greater leisure. But he remained the same, attractive and outpouring, and in London as elsewhere men of all degrees and kinds, students, colleagues, notables in every field, turned to him. Invitations to lectures and meetings multiplied, posts of honor and duty were offered, and the expected feedom for his plans of independent work did not come. The besetting difficulty was his own charm, his own wide competence, his unfailing readiness. He died at the full height of his powers, lamented by a host of friends and admirers, and by none more than by those to whom he had endeared himself at Harvard University.

Frank W. Taussig,
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David Locke Webster	Palo Alto, Cal.
Edwin Bidwell Wilson	Brookline
Robert Williams Wood	Baltimore, Md.
John Zeleny	New Haven, Conn.

Class I., Section III.—*Chemistry*.—49.

Roger Adams	Urbana, Ill.
Wilder Dwight Bancroft	Ithaca, N. Y.
Gregory Paul Baxter	Cambridge
James Alexander Beattie	Brookline
Arthur Alphonzo Blanchard	Cambridge
Marston Taylor Bogert	New York, N. Y.
William Crowell Bray	Berkeley, Cal.
Russell Henry Chittenden	New Haven, Conn.
Arthur Messinger Comey	Cambridge
James Bryant Conant	Cambridge
Tenney Lombard Davis	Norwell
Henry Fay	Boston
George Shannon Forbes	Cambridge
Edward Curtis Franklin	Palo Alto, Cal.
Louis John Gillespie	Cambridge
Lawrence Joseph Henderson	Cambridge
Charles Loring Jackson	Boston
Walter Louis Jennings	Worcester

Grinnell Jones	Cambridge
Frederick George Keyes	Cambridge
Elmer Peter Kohler	Cambridge
Charles August Kraus	Providence, R. I.
Arthur Becket Lamb	Cambridge
Irving Langmuir	Schenectady, N. Y.
Gilbert Newton Lewis	Berkeley, Cal.
Warren Kendall Lewis	Newton
Arthur Dehon Little	Brookline
Duncan Arthur MacInnes	New York, N. Y.
Lafayette Benedict Mendel	New Haven, Conn.
Edward Mueller	Cambridge
Samuel Parsons Mulliken	Cambridge
Charles Edward Munroe	Forest Glen, Md.
Lyman Churchill Newell	Brookline
James Flack Norris	Boston
Arthur Amos Noyes	Pasadena, Cal.
William Albert Noyes	Urbana, Ill.
Samuel Cate Prescott	Brookline
Robert Hallowell Richards	Jamaica Plain
Martin André Rosanoff	Pittsburgh, Pa.
Allan Winter Rowe	Boston
George Scatchard	Cambridge
Miles Standish Sherrill	Winchester
Harry Monmouth Smith	Brookline
Julius Oscar Stieglitz	Chicago, Ill.
Richard Chace Tolman	Pasadena, Cal.
William Hultz Walker	Pasadena, Cal.
Willis Rodney Whitney	Schenectady, N. Y.
Robert Seaton Williams	Cambridge
Alpheus Grant Woodman	Watertown

CLASS I., SECTION IV.—*Technology and Engineering.*—45.

Comfort Avery Adams	Belmont
Bernard Arthur Behrend	Wellesley Hills
William Hubert Burr	New Canaan, Conn.
Vannevar Bush	Belmont

John Joseph Carty	New York, N. Y.
Harry Ellsworth Clifford	Newton
Arthur Powell Davis	Oakland, Cal.
Theodore Harwood Dillon	Cambridge
Philip Drinker	Brookline
Gano Dunn	New York, N. Y.
William Frederick Durand	Palo Alto, Cal.
Charles Leavitt Edgar	Brookline
Gordon Maskew Fair	Cambridge
Frederic Harold Fay	Boston
John Ripley Freeman	Providence, R. I.
John Hays Hammond	New York, N. Y.
William Hovgaard	Brookline
James Robertson Jack	Watertown
Dugald Caleb Jackson	Cambridge
Frank Baldwin Jewett	New York, N. Y.
Lewis Jerome Johnson	Cambridge
Arthur Edwin Kennelly	Cambridge
William Henry Lawrence	Jamaica Plain
Charles Thomas Main	Winchester
Lionel Simeon Marks	Cambridge
Edward Furber Miller	Newton
Johnson O'Connor	Boston
Frederick Law Olmsted	Brookline
Charles Francis Park	Taunton
William Barclay Parsons	New York, N. Y.
Langdon Pearse	Chicago, Ill.
Harold Pender	Philadelphia, Pa.
Greenleaf Whittier Pickard	Newton Center
George Edmond Russell	Arlington
Albert Sauveur	Cambridge
William Sowden Sims	Newport, R. I.
Henry Lloyd Smyth	Watertown
Charles Milton Spofford	Brookline
John F. Stevens	New York, N. Y.
Samuel Wesley Stratton	Cambridge
George Fillmore Swain	Brookline

Edward Pearson Warner	New York, N. Y.
Arthur Edward Wells	Watertown
Robert Spurr Weston	Boston
Joseph Ruggles Worcester	Boston

CLASS II.—*Natural and Physiological Sciences.*—210.

SECTION I.—*Geology, Mineralogy, and Physics of the Globe.*—49.

Wallace Walter Atwood	Worcester
Norman Levi Bowen	Washington, D. C.
Isaiah Bowman	New York, N. Y.
Kirk Bryan	Cambridge
Henry Helm Clayton	Canton
Herdman Fitzgerald Cleland	Williamstown
Reginald Aldworth Daly	Cambridge
Edward Salisbury Dana	New Haven, Conn.
William Morris Davis	Boston
Benjamin Kendall Emerson	Amherst
William Ebenezer Ford	New Haven, Conn.
James Walter Goldthwait	Hanover, N. H.
Louis Caryl Graton	Cambridge
Herbert Ernest Gregory	New Haven, Conn.
William Jackson Humphreys	Washington, D. C.
Ellsworth Huntington	New Haven, Conn.
Robert Tracy Jackson	Peterborough, N. H.
Thomas Augustus Jaggar	Honolulu, H. I.
Douglas Wilson Johnson	New York, N. Y.
Arthur Keith	Washington, D. C.
Alfred Church Lane	Cambridge
Esper Signius Larsen, Jr.	Cambridge
Andrew Cowper Lawson	Berkeley, Cal.
Charles Kenneth Leith	Madison, Wis.
Waldemar Lindgren	Brookline
Frederic Brewster Loomis	Amherst
Alexander George McAdie	Readville
Donald Hamilton McLaughlin	Cambridge
Kirtley Fletcher Mather	Cambridge
John Campbell Merriam	Washington, D. C.

William John Miller	Los Angeles, Cal.
Charles Palache	Cambridge
Percy Edward Raymond	Lexington
Austin Flint Rogers	Palo Alto, Cal.
Robert Wilcox Sayles	Chestnut Hill
Waldemar Theodore Schaller	Washington, D. C.
Charles Schuchert	New Haven, Conn.
William Berryman Scott	Princeton, N. J.
Hervey Woodburn Shimer	Hingham
Frank Bursley Taylor	Fort Wayne, Ind.
Thomas Wayland Vaughan	La Jolla, Cal.
Robert DeCourcy Ward	Cambridge
Charles Hyde Warren	New Haven, Conn.
David White	Washington, D. C.
Herbert Percy Whitlock	New York, N. Y.
Bailey Willis	Palo Alto, Cal.
Arthur Winslow	Boston
John Eliot Wolff	Pasadena, Cal.
Frederick Eugene Wright	Washington, D. C.

Class II, Section II.—*Botany.*—40.

Le Roy Abrams	Stanford University, Cal.
Oakes Ames	North Easton
Joseph Charles Arthur	Lafayette, Ind.
Irving Widmer Bailey	Cambridge
Liberty Hyde Bailey	Ithaca, N. Y.
Edward Wilber Berry	Baltimore, Md.
Nathaniel Lord Britton	New York, N. Y.
Douglas Houghton Campbell	Palo Alto, Cal.
George Perkins Clinton	New Haven, Conn.
Bradley Moore Davis	Ann Arbor, Mich.
Edward Murray East	Jamaica Plain
Rollins Adams Emerson	Ithaca, N. Y.
Alexander William Evans	New Haven, Conn.
Joseph Horace Faull	Cambridge
Merritt Lyndon Fernald	Cambridge
Richard Thornton Fisher	Petersham

Harvey Monroe Hall	Stanford University, Cal.
Robert Almer Harper	New York, N. Y.
Albert Spear Hitchcock	Washington, D. C.
John George Jack	East Walpole
Edward Charles Jeffrey	Cambridge
Willis Linn Jepson	Berkeley, Cal.
Ivan Murray Johnston	Cambridge
Fred Dayton Lambert	Tufts College
Jacob Goodale Lipman	New Brunswick, N. J.
Burton Edward Livingston	Baltimore, Md.
Elmer Drew Merrill	Berkeley, Cal.
Winthrop John Vanleuven Osterhout	New York, N. Y.
George James Peirce	Palo Alto, Cal.
Alfred Rehder	Jamaica Plain
Benjamin Lincoln Robinson	Cambridge
Karl Sax	Jamaica Plain
William Albert Setchell	Berkeley, Cal.
Arthur Bliss Seymour	Cambridge
Elvin Charles Stakman	St. Paul, Minn.
William Codman Sturgis	New York, N. Y.
Roland Thaxter	Cambridge
William Trelease	Urbana, Ill.
William Henry Weston, Jr.	Cambridge
Ernest Henry Wilson	Jamaica Plain

Class II., Section III.—*Zoology and Physiology.*—69.

Nathan Banks	Cambridge
Thomas Barbour	Boston
Francis Gano Benedict	Boston
Henry Bryant Bigelow	Concord
Robert Payne Bigelow	Brookline
Edwin Garrigues Boring	Cambridge
William T. Bovie	Chicago, Ill.
Edward Allen Boyden	University, Ala.
John Louis Bremer	Boston
Charles Thomas Brues	Jamaica Plain
John Wymond Miller Bunker	Belmont

Walter Bradford Cannon	Cambridge
Thorne Martin Carpenter	Boston
William Ernest Castle	Belmont
Charles Value Chapin	Providence, R. I.
Benjamin Preston Clark	Boston
Lemuel Roscoe Cleveland	Jamaica Plain
Edwin Joseph Cohn	Cambridge
Edwin Grant Conklin	Princeton, N. J.
Manton Copeland	Brunswick, Me.
William John Crozier	Cambridge
Joseph Augustine Cushman	Sharon
Charles Benedict Davenport	Cold Spring Harbor, N. Y.
Hallowell Davis	Cambridge
Samuel Randall Detwiler	New York, N. Y.
Raymond Dodge	New Haven, Conn.
Gilman Arthur Drew	Eagle Lake, Fla.
Cecil Kent Drinker	Boston
Herbert McLean Evans	Berkeley, Cal.
Henry Clinton Fall	Tyngsboro
Alexander Forbes	Milton
Joseph Grinnell	Berkeley, Cal.
Samuel Henshaw	Cambridge
Leigh Hoadley	Cambridge
Samuel Jackson Holmes	Berkeley, Cal.
Roy Graham Hoskins	Brookline
Leland Ossian Howard	Washington, D. C.
Herbert Spencer Jennings	Baltimore, Md.
Charles Willison Johnson	Brookline
Charles Atwood Kofoid	Berkeley, Cal.
Frederic Thomas Lewis	Waban
Ralph Stayner Lillie	Chicago, Ill.
Richard Swann Lull	New Haven, Conn.
Edward Laurens Mark	Cambridge
Ernest Gale Martin	Palo Alto, Cal.
Albert Davis Mead	Providence, R. I.
Axel Leonard Melander	New York, N. Y.
Gerrit Smith Miller	Washington, D. C.

Thomas Hunt Morgan	Pasadena, Cal.
Herbert Vincent Neal	Tufts College
Henry Fairfield Osborn	New York, N. Y.
George Howard Parker	Cambridge
William Patten	Hanover, N. H.
Raymond Pearl	Baltimore, Md.
John Charles Phillips	Wenham
Henry Augustus Pilsbry	Philadelphia, Pa.
Frederick Haven Pratt	Wellesley Hills
Herbert Wilbur Rand	Cambridge
Arthur Clarence Redfield	Boston
William Emerson Ritter	Berkeley, Cal.
Alexander Grant Ruthven	Ann Arbor, Mich.
Percy Goldthwait Stiles	Newtonville
John Eliot Thayer	Lancaster
John Broadus Watson	New York, N. Y.
Arthur Wisswald Weysse	Boston
William Morton Wheeler	Jamaica Plain
Edmund Beecher Wilson	New York, N. Y.
Frederick Adams Woods	New York, N. Y.
Robert Mearns Yerkes	Washington, D. C.

CLASS II., SECTION IV.—*Medicine and Surgery.*—52.

Nathaniel Allison	Boston
James Bourne Ayer	Milton
Kenneth Daniel Blackfan	Brookline
Charles Macfie Campbell	Cambridge
Alexis Carrel	New York, N. Y.
David Cheever	Boston
Henry Asbury Christian	Boston
Stanley Cobb	Ponkapoag
Rufus Cole	New York, N. Y.
Harvey Cushing	Brookline
Simon Flexner	New York, N. Y.
James Lawder Gamble	Brookline
Joseph Lincoln Goodale	Boston
Robert Battey Greenough	Boston

Ross Granville Harrison	New Haven, Conn.
Percy Rogers Howe	Boston
William Henry Howell	Baltimore, Md.
Reid Hunt	Boston
Henry Jackson	Boston
Elliott Proctor Joslin	Boston
William Williams Keen	Philadelphia, Pa.
Roger Irving Lee	Brookline
Edwin Allen Locke	Boston
Warfield Theobald Longcope	Baltimore, Md.
Frank Burr Mallory	Brookline
William James Mayo	Rochester, Minn.
James Howard Means	Boston
George Richards Minot	Boston
William Lorenzo Moss	Jamaica Plain
John Howard Mueller	Boston
Robert Bayley Osgood	Boston
Joseph Hershey Pratt	Boston
William Lambert Richardson	Boston
Milton Joseph Rosenau	Brookline
Andrew Watson Sellards	Boston
Theobald Smith	Princeton, N. J.
Torald Hermann Sollmann	Cleveland, Ohio
Charles Wardell Stiles	Washington, D. C.
Richard Pearson Strong	Boston
Fritz Bradley Talbot	Brookline
Edward Wyllys Taylor	Boston
William Sydney Thayer	Baltimore, Md.
Ernest Edward Tyzzer	Wakefield
Frederick Herman Verhoeff	Boston
Henry Pickering Walcott	Cambridge
Joseph Treloar Wearn	Cleveland, Ohio
William Henry Welch	Baltimore, Md.
Benjamin White	Boston
Francis Henry Williams	Boston
Simeon Burt Wolbach	Boston
Horatio Curtis Wood	Philadelphia, Pa.
Hans Zinsser	Boston

CLASS III.—*Moral and Political Sciences.*—181.

SECTION I.—*Theology, Philosophy, and Jurisprudence.*—41.

Joseph Henry Beale	Cambridge
Edgar Sheffield Brightman	Newton Centre
Walter Fenno Dearborn	Cambridge
Edmund Burke Delabarre	Providence, R. I.
Edward Staples Drown	Cambridge
William Harrison Dunbar	Cambridge
William Wallace Fenn	Cambridge
Frederick Perry Fish	Brookline
Thomas Hovey Gage	Worcester
William Henry Paine Hatch	Cambridge
William Ernest Hocking	Cambridge
Charles Evans Hughes	New York, N. Y.
Frederick John Foakes Jackson	New York, N. Y.
Albert Cornelius Knudson	Cambridge
William Lawrence	Boston
Frederick Lawton	Boston
Clarence Irving Lewis	Cambridge
William Caleb Loring	Boston
William McDougall	Durham, N. C.
Edward Caldwell Moore	Cambridge
John Bassett Moore	New York, N. Y.
George Herbert Palmer	Cambridge
Charles Edwards Park	Boston
Leighton Parks	New York, N. Y.
Francis Greenwood Peabody	Cambridge
George Wharton Pepper	Philadelphia, Pa.
Ralph Barton Perry	Cambridge
Roscoe Pound	Watertown
Elihu Root	New York, N. Y.
James Hardy Ropes	Cambridge
Arthur Prentice Rugg	Worcester
James Hugh Ryan	Washington, D. C.
George Augustus Sanderson	Littleton
George Sarton	Cambridge
Austin Wakeman Scott	Cambridge

Willard Learoyd Sperry	Cambridge
Russell Henry Stafford	Brookline
William Cushing Wait	Medford
Eugene Wambaugh	Cambridge
Henry Bradford Washburn	Cambridge
Quincy Wright	Chicago, Ill.

Class III., Section II.—*Philology and Archaeology.*—53.

Francis Greenleaf Allinson	Providence, R. I.
Franz Boas	New York, N. Y.
Ingersoll Bowditch	Jamaica Plain
Carl Darling Buck	Chicago, Ill.
Eugene Watson Burlingame	Albany, N. Y.
Edward Capps	Princeton, N. J.
George Henry Chase	Cambridge
Walter Eugene Clark	Cambridge
Roland Burrage Dixon	Cambridge
Franklin Edgerton	New Haven, Conn.
Jeremiah Denis Mathias Ford	Cambridge
James Geddes, Jr.	Brookline
Charles Hall Grandgent	Cambridge
Louis Herbert Gray	New York, N. Y.
William Chase Greene	Cambridge
Charles Burton Gulick	Cambridge
Roy Kenneth Hack	Cincinnati, O.
William Arthur Heidel	Middletown, Conn.
George Lincoln Hendrickson	New Haven, Conn.
Bert Hodge Hill	Athens, Greece
Elijah Clarence Hills	Berkeley, Cal.
William Henry Holmes	Washington, D. C.
Earnest Albert Hooton	Cambridge
Edward Washburn Hopkins	New Haven, Conn.
William Guild Howard	Cambridge
Aleš Hrdlička	Washington, D. C.
Eugene Xavier Louis Henry Hyvernat	Washington, D. C.
Carl Newell Jackson	Cambridge
James Richard Jewett	Cambridge

Alfred Vincent Kidder	Washington, D. C.
Alfred Louis Kroeber	Berkeley, Cal.
Kirsopp Lake	Cambridge
Henry Roseman Lang	New Haven, Conn.
Charles Rockwell Lanman	Cambridge
David Gordon Lyon	Cambridge
Clifford Herschel Moore	Cambridge
George Foot Moore	Cambridge
William Albert Nitze	Chicago, Ill.
Chandler Rathfon Post	Cambridge
Edward Kennard Rand	Cambridge
George Andrew Reisner	Cambridge
Edward Robinson	New York, N.. Y.
Fred Norris Robinson	Cambridge
Rudolph Schevill	Berkeley, Cal.
Herbert Weir Smyth	Cambridge
Herbert Joseph Spinden	Brooklyn, N. Y.
Franklin Bache Stephenson	Washington, D. C.
Charles Cutler Torrey	New Haven, Conn.
Alfred Marston Tozzer	Cambridge
Joshua Whatmough	Cambridge
Ernest Hatch Wilkins	Oberlin, Ohio
Clark Wissler	New York, N. Y.
James Haughton Woods	Cambridge

CLASS III., SECTION III.—*Political Economy and History.*—43.

Charles McLean Andrews	New Haven, Conn.
James Phinney Baxter, 3d	Cambridge
Carl Lotus Becker	Ithaca, N. Y.
Robert Pierpont Blake	Cambridge
Charles Jesse Bullock	Cambridge
Thomas Nixon Carver	Cambridge
Edward Channing	Cambridge
John Bates Clark	New York, N. Y.
Arthur Harrison Cole	Cambridge
Richard Henry Dana	Cambridge
Clive Day	New Haven, Conn.

Davis Rich Dewey	Cambridge
William Yandell Elliott	Cambridge
Ephraim Emerton	Cambridge
Henry Walcott Farnam	New Haven, Conn.
Max Farrand	San Gabriel, Cal.
William Scott Ferguson	Cambridge
Irving Fisher	New Haven, Conn.
William Cameron Forbes	Milton
Worthington Chauncey Ford	Cambridge
Edwin Francis Gay	Cambridge
Frank Johnson Goodnow	Baltimore, Md.
Evarts Boutell Greene	New York, N. Y.
Albert Bushnell Hart	Cambridge
Charles Homer Haskins	Cambridge
Charles Downer Hazen	New York, N. Y.
Arthur Norman Holcombe	Cambridge
George La Piana	Cambridge
Abbott Lawrence Lowell	Cambridge
William MacDonald	New York, N. Y.
Charles Howard McIlwain	Cambridge
Roger Bigelow Merriman	Cambridge
Samuel Eliot Morison	Boston
William Bennett Munro	Boston
Warren Milton Persons	New York, N. Y.
Michael Ivanovich Rostovtzeff	New Haven, Conn.
Arthur Meier Schlesinger	Cambridge
John Osborne Sumner	Boston
Frank William Taussig	Cambridge
Frederick Jackson Turner	San Gabriel, Cal.
Westel Woodbury Willoughby	Baltimore, Md.
George Grafton Wilson	Cambridge
George Parker Winship	Charles River

Class III., Section IV.—*Literature and the Fine Arts.*—44.

Irving Babbitt	Cambridge
George Pierce Baker	New Haven, Conn.
Frank Weston Benson	Salem

Le Baron Russell Briggs	Bournedale
Charles Allerton Coolidge	Boston
Frederick Shepard Converse	Westwood
Charles Townsend Copeland	Cambridge
Wilberforce Eames	New York, N. Y.
William Emerson	Cambridge
Arthur Fairbanks	Hanover, N. H.
Frank Edgar Farley	Middletown, Conn.
Edward Waldo Forbes	Cambridge
Daniel Chester French	New York, N. Y.
Wallace Goodrich	Boston
Robert Grant	Boston
Morris Gray	Boston
Chester Noyes Greenough	Cambridge
Edward Burlingame Hill	Cambridge
Charles Hopkinson	Manchester
Mark Antony DeWolfe Howe	Boston
Archer Milton Huntington	New York, N. Y.
George Lyman Kittredge	Cambridge
William Coolidge Lane	Cambridge
John Ellerton Lodge	Boston
Charles Martin Tornov Loeffler	Medfield
John Livingston Lowes	Cambridge
Charles Donagh Maginnis	Brookline
Albert Matthews	Boston
Harold Murdock	Brookline
William Allan Neilson	Northampton
Curtis Hidden Page	Gilmanton, N. H.
William Lyon Phelps	New Haven, Conn.
Arthur Kingsley Porter	Cambridge
Herbert Putnam	Washington, D. C.
Edwin Arlington Robinson	New York, N. Y.
Denman Waldo Ross	Cambridge
Paul Joseph Sachs	Cambridge
Ellery Sedgwick	Boston
Henry Dwight Sedgwick	Boston
Richard Clipston Sturgis	Boston
Edmund C. Tarbell	Boston

Charles Howard Walker	Boston
Owen Wister	Philadelphia, Pa.
Charles Henry Conrad Wright	Cambridge

ASSOCIATES.—33.

Charles Francis Adams	Concord
Francis Noyes Balch	Jamaica Plain
Franklin Greene Balch	Boston
Charles Foster Batchelder	Cambridge
Charles Francis Dorr Belden	Jamaica Plain
Roland William Boyden	Beverly
Frederick Pickering Cabot	Boston
William Brooks Cabot	Boston
John Candler Cobb	Milton
Howard Coonley	Milton
John Albert Cousens	Tufts College
Henry Winchester Cunningham	Milton
Charles Ernest Fay	Somerville
William Lusk Webster Field	Milton
Francis Russell Hart	Boston
Edward Jackson Holmes	Boston
William James	Cambridge
Nathaniel Thayer Kidder	Milton
Everett Morss	Boston
Robert Lincoln O'Brien	Dedham
Thomas Nelson Perkins	Westwood
Andrew James Peters	Jamaica Plain
Anthony John Philpott	Arlington
Arthur Stanwood Pier	Hyde Park
Alfred Lawrence Ripley	Andover
Odin Roberts	Boston
Jeremiah Smith, Jr.	Cambridge
Payson Smith	Brookline
Charles Henry Taylor	Boston
Eliot Wadsworth	Boston
Edwin Sibley Webster	Brookline
Edmund Allen Whitman	Cambridge
Benjamin Loring Young	Weston

FOREIGN HONORARY MEMBERS.—98.

(Number limited to one hundred.)

CLASS I.—*Mathematical and Physical Sciences.*—33.

SECTION I.—*Mathematics and Astronomy.*—9.

Arthur Stanley Eddington	Cambridge
Jacques Salomon Hadamard	Paris
Godfrey Harold Hardy	Oxford
Ejnar Hertzsprung	Leyden
Tullio Levi-Civita	Rome
Charles Emile Picard	Paris
Willem de Sitter	Leyden
Charles Jean de la Vallée Poussin	Louvain
Hermann Weyl	Zürich

CLASS I., SECTION II.—*Physics.*—9.

Vilhelm Frimann Koren Bjerknes	Oslo
Albert Einstein	Berlin
James Franck	Berlin
Abram F. Joffé	Leningrad
Sir Joseph Larmor	Cambridge
Friedrich Paschen	Berlin
Max Planck	Berlin
Sir Ernest Rutherford	Cambridge
Sir Joseph John Thomson	Cambridge

CLASS I., SECTION III.—*Chemistry.*—8.

Johannes N. Brönsted	Copenhagen
Peter Debye	Zürich
Fritz Haber	Berlin
Henri Louis Le Chatelier	Paris
Archibald Byron Macallum	London, Ontario
Wilhelm Ostwald	Leipzig
Sören Peter Lauritz Sörensen	Copenhagen
Heinrich Wieland	Munich

Class I., Section IV.—*Technology and Engineering.*—7.

Joseph Jacques Césaire Joffre	Paris
Maurice d'Ocagne	Paris
Ludwig Prandtl	Göttingen
Emil Probst	Karlsruhe
Aurel Stodola	Zürich
Vsevolod Evgenievich Timonoff	Leningrad
William Cawthorne Unwin	London

Class II.—*Natural and Physiological Sciences.*—35.

Section I.—*Geology, Mineralogy, and Physics of the Globe.*—10.

Frank Dawson Adams	Montreal
Charles Barrois	Lille
Waldemar Christofer Brögger	Oslo
Léon William Collet	Geneva
Viktor Goldschmidt	Heidelberg
Albert Heim	Zürich
Emmanuel de Margerie	Paris
Gustaf Adolf Frederik Molengraaff	Delft
Sir William Napier Shaw	London
Johan Herman Lie Vogt	Trondhjem

Class II., Section II.—*Botany.*—8.

John Briquet	Geneva
Adolf Engler	Berlin
Carl Hansen Ostenfelt	Copenhagen
Alfred Barton Rendle	London
Otto Renner	Jena
Ignatz Urban	Berlin
Hugo de Vries	Luntern
Richard Wettstein	Vienna

Class II., Section III.—*Zoology and Physiology.*—9.

Francis Arthur Bather	London
George Albert Boulenger	Brussels
Maurice Caullery	Paris
Louis Dollo	Brussels

Wolfgang Köhler	Berlin
Louis Édouard Lapicque	Paris
George Henry Falkiner Nuttall	Cambridge
Charles Tate Regan	London
D'Arcy Wentworth Thompson	St. Andrews

CLASS II., SECTION IV.—*Medicine and Surgery.*—8.

Henry Hallett Dale	London
Sir Thomas Barlow, Bart.	London
Sir Robert Jones, Bart.	Liverpool
Mikinosuke Miyajima	Tokyo
Friedrich von Müller	Munich
Francis John Shepherd	Montreal
Sir Charles Scott Sherrington	Oxford
Sir Arnold Theiler	London

CLASS III.—*Moral and Political Sciences.*—30.

SECTION I.—*Theology, Philosophy, and Jurisprudence.*—9.

Henri Louis Bergson	Paris
Francis Crawford Burkitt	Cambridge
Benedetto Croce	Naples
Étienne Gilson	Melun
Edmund Husserl	Freiburg i. B.
Raymond Poincaré	Paris
Rt. Hon. Sir Frederick Pollock, Bart.	London
Rufus Daniel Isaacs, Marquess of Reading	London
Joseph Redlich	Vienna

CLASS III., SECTION II.—*Philology and Archaeology.*—7.

Wilhelm Dörpfeld	Athens
Henri Guy	Grenoble
Hermann Georg Jacobi	Bonn
Arthur Anthony Macdonell	Oxford
Alfred Percival Maudslay	Hereford
Hanns Oertel	Munich
Ramon Menendez Pidal	Madrid

CLASS III., SECTION III.—*Political Economy and History.*—5.

Léon Duguit	Bordeaux
Karl Pearson	London
Arthur Cecil Pigou	Cambridge
Henri Pirenne	Ghent
Rt. Hon. Sir George Otto Trevelyan, Bart.	London

CLASS III., SECTION IV.—*Literature and the Fine Arts.*—9.

Joseph Bédier	Paris
Godfrey Rathbone Benson, Baron Charnwood	Lichfield
Alfredo Casella	Rome
Paul Hazard	Paris
Jean Adrien Antoine Jules Jusserand	Paris
Rudyard Kipling	Burwash
Victor Laloux	Paris
Gilbert Murray	Oxford
Henri Rabaud	Paris

INDEX OF MEMBERS.

The letters A, F, and FHM refer to the lists of Associates, Fellows, and Foreign Honorary Members, respectively. The class and section are indicated by the numerals following.

Abbot, C. G. F, I: 1
Abrams, L. R. F, II: 2
Adams, C. A. F, I: 4
Adams, C. F. A
Adams, F. D. FHM, II: 1
Adams, R. F, I: 3
Adams, W. S. F, I: 1
Agassiz, G. R. F, I: 1
Allinson, F. G. F, III: 2
Allison, N. F, II: 4
Ames, A., Jr. F, I: 2
Ames, J. S. F, I: 2
Ames, O. F, II: 2
Andrews, C. M. F, III: 3
Archibald, R. C. F, I: 1
Arthur, J. C. F, II: 2
Atwood, W. W. F, II: 1
Ayer, J. B. F, II: 4
Babbitt, I. F, III: 4
Bailey I. W. F, II: 2
Bailey, L. H. F, II: 2
Bailey, S. I. F, I: 1
Baker, G. P. F, III: 4
Balch, F. G. A
Balch, F. N. A
Bancroft, W. D. F, I: 3
Banks, N. F, II: 3
Barbour, T. F, II: 3
Barlow, Sir T. FHM, II: 4
Barnett, S. J. F, I: 2
Barrois, C. FHM, II: 1
Barus, C. F, I: 2
Batchelder, C. F. A
Bather, F. A. FHM, II: 3
Bauer, L. A. F, I: 2
Baxter, G. P. F, I: 3
Baxter, J. P., 3d. F, III: 3
Beale, J. H. F, III: 1
Beattie, J. A. F, I: 3
Becker, C. L. F, III: 3
Bédier, J. FHM, III: 4
Behrend, B. A. F, I: 4
Belden, C. F. D. A
Benedict, F. G. F, II: 3
Benson, F. W. F, III: 4
Bergson, H. L. FHM, III: 1
Berry, E. W. F, II: 2
Bigelow, H. B. F, II: 3
Bigelow, R. P. F, II: 3
Birkhoff, G. D. F, I: 1
Bjerknes, V. F. K. FHM, I: 2
Blackfan, K. D. F, II: 4
Blake, R. P. F, III: 3
Blanchard, A. A. F, I: 3
Boas, F. F, III: 2
Bogert, M. T. F, I: 3
Boring, E. G. F, II: 3
Boulenger, G. A. FHM, II: 3
Bovie, W. T. F, II: 3
Bowditch, I. F, III: 2
Bowen, N. L. F, II: 1
Bowman, I. F, II: 1
Boyden, E. A. F, II: 3
Boyden, R. W. A
Bray, W. C. F, I: 3
Bremer, J. L. F, II: 3
Bridgman, P. W. F, I: 2
Briggs, L. B. R. F, III: 4
Brightman, E. S. F, III: 1
Briquet, J. FHM, II: 2
Britton, N. L. F, II: 2
Brögger, W. C. FHM, II: 1
Brönsted, J. N. FHM, I: 3
Brown, E. W. F, I: 1

Brues, C. T. F, II: 3
Bryan, K. F, II: 1
Buck, C. D. F, III: 2
Bullock, C. J. F, III: 3
Bunker, J. W. M. F, II: 3
Burkitt, F. C. FHM, III: 1
Burlingame, E. W. F, III: 2
Burr, W. H. F, I: 4
Bush, V. F, I: 4
Byerly, W. E. F, I: 1
Cabot, F. P. A
Cabot, W. B. A
Cady, W. G. F, I: 2
Cajori, F. F, I: 1
Campbell, C. M. F, II: 4
Campbell, D. H. F, II: 2
Campbell, G. A. F, I: 2
Campbell, L. L. F, I: 2
Campbell, W, W. F, I: 1
Cannon, W. B. F, II: 3
Capps, E. F, III: 2
Carpenter, T. M. F, II: 3
Carrel, A. F, II: 4
Carty, J. J. F, I: 4
Carver, T. N. F, III: 3
Casella, A. FHM, III: 4
Castle, W. E. F, II: 3
Caullery, M. FHM, II: 3
Chaffee, E. L. F, I: 2
Channing, E. F, III: 3
Chapin, C. V. F, II: 4
Charnwood, Lord. FHM, III: 4
Chase, G. H. F, III: 2
Cheever, D. F, II: 4
Chittenden, R. H. F, I: 3
Christian, H. A. F, II: 4
Clark, B. P. F, II: 3
Clark, J. B. F, III: 3
Clark, W. E. F, III: 2
Clayton, H. H. F, II: 1
Cleland, H. F. F, II: 1
Cleveland, L. R. F, II: 3
Clifford, H. E. F, I: 4
Clinton, G. P. F, II: 2
Cobb, J. C. A
Cobb, S. F, II: 4
Cohn, E. J. F, II: 3
Cole, A. H. F, III: 3
Cole, R. F, II: 4
Collet, L. W. FHM, II: 1
Comey, A. M. F, I: 3
Compton, A. H. F, I: 2
Comstock, D. F. F, I: 2
Comstock, G. C. F, I: 1
Conant, J. B. F, I: 3
Conklin, E. G. F, II: 3
Converse, F. S. F, III: 4
Coolidge, C. A. F, III: 4
Coolidge, J. L. F, I: 1
Coolidge, W. D. F, I: 2
Coonley, H. A
Copeland, C. T. F, III: 4
Copeland, M. F, II: 3
Cousens, J. A. A
Crew, H. F, I: 2
Croce, B. FHM, III: 1
Crozier, W. J. F, II: 3
Cunningham, H. W. A
Cushing, H. F, II: 4
Cushman, J. A. F, II: 3
Dale, H. H. FHM, II: 4
Daly, R. A. F, II: 1
Dana, E. S. F, II: 1
Dana, R. H. F, III: 3
Davenport, C. B. F, II: 3
Davis, A. P. F, I: 4
Davis, B. M. F, II: 2
Davis, H. F, II: 3
Davis, H. N. F, I: 2
Davis, T. L. F, I: 3
Davis, W. M. F, II: 1
Davisson, C. J. F, I: 2
Day, A. L. F, I: 2
Day, C. F, III: 3
Dearborn, W. F. F, III: 1
Debye, P. FHM, I: 3
Delabarre, E. B. F, III: 1
Detwiler, S. R. F, II: 3

Dewey, D. R. F, III: 3
Dickson, L. E. F, I: 1
Dillon, T. H. F, I: 4
Dixon, R. B. F, III: 2
Dodge, R. F, II: 3
Dörpfeld, W. F, III: 2
Dollo, L. FHM, II: 3
Drew, G. A. F, II: 3
Drinker, C. K. F, II: 3
Drinker, P. F, I: 4
Drisko, W. J. F, I: 2
Drown, E. S. F, III: 1
Duane, W. F, I: 2
Duff, A. W. F, I: 2
Duguit, L. FHM, III: 3
Dunbar, W. H. F, III: 1
Dunn, G. F, I: 4
Durand, W. F. F, I: 4
Eames, W. F, III: 4
East, E. M. F, II: 2
Eddington, A. S. FHM, I: 1
Edgar, C. L. F, I: 4
Edgerton, F. F, III: 2
Einstein, A. FHM, I: 2
Elliott, W. Y. F, III: 3
Emerson, B. K. F, II: 1
Emerson, R. A. F, II: 2
Emerson, W. F, III: 4
Emerton, E. F, III: 3
Engler, A. FHM, II: 2
Evans, A. W. F, II: 2
Evans, H. M. F, II: 3
Ewell, A. W. F, I: 2
Fair, G. M. F, I: 4
Fairbanks, A. F, III: 4
Fall, H. C. F, II: 3
Farley, F. E. F, III: 4
Farnam, H. W. F, III: 3
Farrand, M. F, III: 3
Faull, J. H. F, II: 2
Fay, C. E. A
Fay, F. H. F, I: 4
Fay, H. F, I: 3
Fenn, W. W. F, III: 1
Ferguson, W. S. F, III: 3
Fernald, M. L. F, II: 2
Field, W. L. W. A
Fish, F. P. F, III: 1
Fisher, I. F, III: 3
Fisher, R. T. F, II: 2
Flexner, S. F, II: 4
Forbes, A. F, II: 3
Forbes, E. W. F, III: 4
Forbes, G. S. F, I: 3
Forbes, W. C. F, III: 3
Ford, J. D. M. F, III: 2
Ford, W. C. F, III: 3
Ford, W. E. F, II: 1
Fox, P. F, I: 1
Franck, J. FHM, I: 2
Franklin, E. C. F, I: 3
Franklin, F. F, I: 1
Franklin, P. F, I: 1
Freeman, J. R. F, I: 4
French, D. C. F, III: 4
Frost, E. B. F, I: 1
Gage, T. H. F, III: 1
Gamble, J. L. F, II: 4
Gay, E. F. F, III: 3
Geddes, J., Jr. F, III: 2
Gillespie, L. J. F, I: 3
Gilson, E. FHM, III: 1
Goldschmidt, V. F, II: 1
Goldthwait, J. W. F, II: 1
Goodale, J. L. F, II: 4
Goodnow, F. J. F, III: 3
Goodrich, W. F, III: 4
Goodwin, H. M. F, I: 2
Grandgent, C. H. F, III: 2
Grant, R. F, III: 4
Graton, L. C. F, II: 1
Graustein, W. C. F, I: 1
Gray, L. H. F, III: 2
Gray, M. F, III: 4
Greene, E. B. F, III: 3
Greene, W. C. F, III: 2
Greenough, C. N. F, III: 4
Greenough, R. B. F, II: 4

Gregory, H. E. F, II: 1
Grinnell, J. F, II: 3
Gulick, C. B. F, III: 2
Guy, H. FHM, III: 2
Haber, F. FHM, I: 3
Hack, R. K. F, III: 2
Hadamard, J. S. FHM, I: 1
Hale, G. E. F, I: 2
Hall, E. H. F, I: 2
Hall, H. M. F, II: 2
Hammond, J. H. F, I: 4
Hardy, A. C. F, I: 2
Hardy, G. H. FHM, I: 1
Haring, C. H. F, III: 3
Harper, R. A. F, II: 2
Harrison, R. G. F, II: 4
Hart, A. B. F, III: 3
Hart, F. R. A
Haskins, C. H. F, III: 3
Hatch, W. H. P. F, III: 1
Hayes, H. V. F, I: 2
Hazard, P. FHM, III: 4
Hazen, C. D. F, III: 3
Heidel, W. A. F, III: 2
Heim, A. FHM, II: 1
Henderson, L. J. F, I: 3
Hendrickson, G. L. F, III: 2
Henshaw, S. F, II: 3
Hertzsprung, E. FHM, I: 1
Hill, B. H. F, III: 2
Hill, E. B. F, III: 4
Hills, E. C. F, III: 2
Hitchcock, A. S. F, II: 2
Hitchcock, F. L. F, I: 1
Hoadley, L. F, II: 3
Hocking, W. E. F, III: 1
Holcombe, A. N. F, III: 3
Holmes, E. J. A
Holmes, S. J. F, II: 3
Holmes, W. H. F, III: 2
Hooton, E. A. F, III: 2
Hopkins, E. W. F, III: 2
Hopkinson, C. F, III: 4
Hoskins, R. G. F, II: 3
Hovgaard, W. F, I: 4
Howard, L. O. F, II: 3
Howard, W. G. F, III: 2
Howe, M. A. DeW. F, III: 4
Howe, P. R. F, II: 4
Howell, W. H. F, II: 4
Hrdlicka, A. F, III: 2
Hubbard, J. C. F, I: 2
Hughes, C. E. F, III: 1
Hull, G. F. F, I: 2
Humphreys, W. J. F, II: 1
Hunt, R. F, II: 4
Huntington, A. M. F, III: 4
Huntington, E. F, II: 1
Huntington, E. V. F, I: 1
Husserl, E. FHM, III: 1
Hutchins, C. C. F, I: 2
Hyvernat, E. X. L. H. F, III: 2
Ives, F. E. F, I: 2
Ives, J. E. F, I: 2
Jack, J. G. F, II: 2
Jack, J. R. F, I: 4
Jackson, C. L. F, I: 3
Jackson, C. N. F, III: 2
Jackson, D. F, I: 1
Jackson, D. C. F, I: 4
Jackson, F. J. F. F, III: 1
Jackson, H. F, II: 4
Jackson, R. T. F, II: 1
Jacobi, H. G. FHM, III: 2
Jacques, W. W. F, I: 2
Jaggar, T. A. F, II: 1
James, W. A
Jeffrey, E. C. F, II: 2
Jennings, H. S. F, II: 3
Jennings, W. L. F, I: 3
Jepson, W. L. F, II: 2
Jewett, F. B. F, I: 4
Jewett, J. R. F, III: 2
Joffé, A. F. FHM, I: 2
Joffre, J. J. C. FHM, I: 4
Johnson, C. W. F, II: 3
Johnson, D. W. F, II: 1
Johnson, L. J. F, I: 4

Johnston, I. M. F, II: 2
Jones, G. F, I: 3
Jones, Sir R. FHM, II: 4
Joslin, E. P. F, II: 4
Jusserand, J. A. A. J. FHM, III: 4
Keen, W. W. F, II: 4
Keith, A. F, II: 1
Kellogg, O. D. F, I: 1
Kemble, E. C. F, I: 2
Kennelly, A. E. F, I: 4
Kent, N. A. F, I: 2
Keyes, F. G. F, I: 3
Kidder, A. V. F, III: 2
Kidder, N. T. A
King, E. S. F, I: 1
Kipling, R. FHM, III: 4
Kittredge, G. L. F, III: 4
Knudson, A. C. F, III: 1
Köhler, W. FHM, II: 3
Kofoid, C. A. F, II: 3
Kohler, E. P. F, I: 3
Kraus, C. A. F, I: 3
Kroeber, A. L. F, III: 2
Lake, K. F, III: 2
Laloux, V. FHM, III: 4
Lamb, A. B. F, I: 3
Lambert, F. D. F, II: 2
Lampland, C. O. F, I: 1
Lane, A. C. F, II: 1
Lane, W. C. F, III: 4
Lang, H. R. F, III: 2
Langmuir, I. F, I: 3
Lanman, C. R. F, III: 2
La Piana, G. F, III: 3
Lapicque, L. E. FHM, II: 3
Larmor, Sir J. FHM, I: 2
Larsen, E. S. F, II: 1
Lawrence, W. F, III: 1
Lawrence, W. H. F, I: 4
Laws, F. A. F, I: 2
Lawson, A. C. F, II: 1
Lawton, F. F, III: 1
Le Chatelier, H. L. FHM, I: 3
Lee, R. I. F, II: 4
Lefavour, H. F, I: 2
Leith, C. K. F, II: 1
Levi-Civita, T. FHM, I: 1
Lewis, C. I. F, III: 1
Lewis, F. T. F, II: 3
Lewis, G. N. F, I: 3
Lewis, W. K. F, I: 3
Lillie, R. S. F, II: 3
Lindgren, W. F, II: 1
Lipman, J. G. F, II: 2
Little, A. D. F, I: 3
Livingston, B. E. F, II: 2
Locke, E. A. F, II: 4
Lodge, J. E. F, III: 4
Loeffler, C. M. T. F, III: 4
Longcope, W. T. F, II: 4
Loomis, F. B. F, II: 1
Loring, W. C. F, III: 1
Lowell, A. L. F, III: 3
Lowes, J. L. F, III: 4
Lull, R. S. F, II: 3
Luyten, W. J. F, I: 1
Lyman, T. F, I: 2
Lyon, D. G. F, III: 2
McAdie, A. G. F, II: 1
Macallum, A. B. FHM, I: 3
MacDonald, W. F, III: 3
Macdonell, A. A. FHM, III: 2
McDougall, W. F, III: 1
McIlwain, C. H. F, III: 3
MacInnes, D. A. F, I: 3
McLaughlin, D. H. F, II: 1
Maginnis, C. D. F, III: 4
Main, C. T. F, I: 4
Mallory, F. B. F, II: 4
Margerie, E. de. FHM, II: 1
Mark, E. L. F, II: 3
Marks, L. S. F, I: 4
Martin, E. G. F, II: 3
Mather, K. F. F, II: 1
Mathews, E. B. F, II: 1
Matthews, A. F, III: 4
Maudslay, A. P. FHM, III: 2
Mayo, W. J. F, II: 4

Mead, A. D. F, II: 3
Means, J. H. F, II: 4
Melander, A. L. F, II: 3
Mendel, L. B. F, I: 3
Merriam, J. C. F, II: 1
Merrill, E. D. F, II: 2
Merriman, R. B. F, III: 3
Merritt, E. G. F, I: 2
Michelson, A. A. F, I: 2
Miller, D. C. F, I: 2
Miller, E. F. F, I: 4
Miller, G. A. F, I: 1
Miller, G. S. F, II: 3
Miller, J. A. F, I: 1
Miller, W. J. F, II: 1
Millikan, R. A. F, I: 2
Minot, G. R. F, II: 4
Mitchell, S. A. F, I: 1
Miyajima, M. FHM, II: 4
Molengraaff, G. A. F. FHM, II: 1
Moore, C. H. F, III: 2
Moore, C. L. E. F, I: 1
Moore, E. C. F, III: 1
Moore, E. H. F, I: 1
Moore, G. F. F, III: 2
Moore, J. B. F, III: 1
Morgan, T. H. F, II: 3
Morison, S. E. F, III: 3
Morley, F. F, I: 1
Morse, H. W. F, I: 2
Morse, M. F, I: 1
Morss, E. A
Moss, W. L. F, II: 4
Moulton, F. R. F, I: 1
Mueller, E. F, I: 3
Müller, F. von. FHM, II: 4
Mueller, J. H. F, II: 4
Mulliken, S. P. F, I: 3
Munro, W. B. F, III: 3
Munroe, C. E. F, I: 3
Murdock, H. F, III: 4
Murray, G. FHM, III: 4
Neal, H. V. F, II: 3
Neilson, W. A. F, III: 4
Newell, L. C. F, I: 3
Nichols, E. L. F, I: 2
Nitze, W. A. F, III: 2
Norris, J. F. F, I: 3
Norton, C. L. F, I: 2
Noyes, A. A. F, I: 3
Noyes, W. A. F, I: 3
Nuttall, G. H. F. FHM, II: 3
O'Brien, R. L. A
d'Ocagne, M. FHM, I: 4
O'Connor, J. F, I: 4
Oertel, H. FHM, III: 2
Olmsted, F. L. F, I: 4
Osborn, H. F. F, II: 3
Osgood, R. B. F, II: 4
Ostenfelt, C. H. FHM, II: 2
Osterhout, W. J. V. F, II: 2
Ostwald, W. FHM, I: 3
Page, C. H. F, III: 4
Palache, C. F, II: 1
Palmer, G. H. F, III: 1
Park, C. E. F, III: 1
Park, C. F. F, I: 4
Parker, G. H. F, II: 3
Parks, L. F, III: 1
Parsons, W. B. F, I: 4
Paschen, F. FHM, I: 2
Patten, W. F, II: 3
Peabody, F. G. F, III: 1
Pearl, R. F, II: 3
Pearse, L. F, I: 4
Pearson, K. FHM, III: 3
Peirce, G. J. F, II: 2
Pender, H. F, I: 4
Pepper, G. W. F, III: 1
Perkins, T. N. A
Perry, R. B. F, III: 1
Persons, W. M. F, III: 3
Peters, A. J. A
Phelps, W. L. F, III: 4
Phillips, H. B. F, I: 1
Phillips, J. C. F, II: 3
Philpott, A. J. A
Picard, C. E. FHM, I: 1

Pickard, G. W. F, I: 4
Pickering, W. H. F, I: 1
Pidal, R. M. FHM, III: 2
Pier, A. S. A
Pierce, G. W. F, I: 2
Pigou, A. C. FHM, III: 3
Pilsbry, H. A. F, II: 3
Pirenne, H. FHM, III: 3
Planck, M. FHM, I: 2
Plaskett, H. H. F, I: 1
Poincaré, R. FHM, III: 1
Pollock, Sir F. FHM, III: 1
Poor, C. L. F, I: 1
Porter, A. K. F, III: 4
Post, C. R. F, III: 2
Pound, R. F, III: 1
Prandtl, L. FHM, I: 4
Pratt, F. H. F, II: 3
Pratt, J. H. F, II: 4
Prescott, S. C. F, I: 3
Probst, E. FHM, I: 4
Pupin, M. I. F, I: 2
Putnam, H. F, III: 4
Rabaud, H. FHM, III: 4
Rand, E. K. F, III: 2
Rand, H. W. F, II: 3
Raymond, P. E. F, II: 1
Reading, Lord. FHM, III: 1
Redfield, A. C. F, II: 3
Redlich, J. FHM, III: 1
Regan, C. T. FHM, II: 3
Rehder, A. F, II: 2
Reisner, G. A. F, III: 2
Rendle, A. B. FHM, II: 2
Renner, O. FHM, II: 2
Richards, R. H. F, I: 3
Richardson, R. G. D. F, I: 1
Richardson, W. L. F, II: 4
Ripley, A. L. A
Ritter, W. E. F, II: 3
Roberts, O. A
Robinson, B. L. F. II: 2
Robinson, E. F, III: 2
Robinson, E. A. F, III: 4
Robinson, F. N. F, III: 2
Rogers, A. F. F, II: 1
Root, E. F, III: 1
Ropes, J. H. F, III: 1
Rosanoff, M. A. F, I: 3
Rosenau, M. J. F, II: 4
Ross, D. W. F, III: 4
Rostovtzeff, M. I. F, III: 3
Rowe, A. W. F, I: 3
Rugg, A. P. F, III: 1
Russell, G. E. F. I: 4
Russell, H. N. F, I: 1
Rutherford, Sir E. FHM, I: 2
Ruthven, A. G. F, II: 3
Ryan, J. H. F, III: 1
Sachs,P. J. F, III: 4
Sanderson, G. A. F, III: 1
Sarton, G. F, III: 1
Saunders, F. A. F, I: 2
Sauveur, A. F, I: 4
Sax, K. F, II: 2
Sayles, R. W. F, II: 1
Scatchard, G. F, I: 3
Schaller, W. T. F, II: 1
Schevill, R. F, III: 2
Schlesinger, A. M. F, III: 3
Schlesinger, F. F, I: 1
Schuchert, C. F, II: 1
Scott, A. W. F, III: 1
Scott, W. B. F, II: 1
Sedgwick, E. F, III: 4
Sedgwick, H. D. F, III: 4
Sellards, A. W. F, II: 4
Setchell, W. A. F, II: 2
Seymour, A. B. F, II: 2
Shapley, H. F, I: 1
Shaw, Sir W. N. FHM, II: 1
Shepherd, F. J. FHM, II: 4
Sherrill, M. S. F, I: 3
Sherrington, Sir C. S. FHM, II: 4
Shimer, H. W. F, II: 1
Sims, W. S. F, I: 4
Sitter, W. de. FHM, I: 1
Slater, J. C. F, I: 2

Slipher, V. M. F, I: 1
Slocum, F. F, I: 1
Smith, H. M. F, I: 3
Smith, J., Jr. A
Smith, P. A
Smith, T. F, II: 4
Smyth, H. L. F, I: 4
Smyth, H. W. F, III: 2
Snyder, V. F, I: 1
Sörensen, S. P. L. FHM, I: 3
Sollmann, T. H. F, II: 4
Sperry, W. L. F, III: 1
Spinden, H. J. F, III: 2
Spofford, C. M. F, I: 4
Stafford, R. H. F, III: 1
Stakman, E. C. F, II: 2
Stebbins, J. F, I: 1
Stephenson, F. B. F, III: 2
Stetson, H. T. F, I: 1
Stevens, J. F. F, I: 4
Stieglitz, J. O. F, I: 3
Stiles, C. W. F, II: 4
Stiles, P. G. F, II: 3
Stodola, A. FHM, I: 4
Stone, J. S. F, I: 2
Stratton, S. W. F, I: 4
Strong, R. P. F, II: 4
Struik, D. J. F, I: 1
Sturgis, R. C. F, III: 4
Sturgis, W. C. F, II: 2
Sumner, J. O. F, III: 3
Swain, G. F. F, I: 4
Taber, H. F, I: 1
Talbot, F. B. F, II: 4
Tamarkin, J. D. F, I: 1
Tarbell, E. C. F, III: 4
Taussig, F. W. F, III: 3
Taylor, C. H. A
Taylor, E. W. F, II: 4
Taylor, F. B. F, II: 1
Thaxter, R. F, II: 2
Thayer, J. E. F, II: 3
Thayer, W. S. F, II: 4
Theiler, Sir A. FHM, II: 4
Thompson, D'A. W. FHM, II: 3
Thompson, M. deK. F, I: 2
Thomson, E. F, I: 2
Thomson, Sir J. J. FHM, I: 2
Timonoff, V. E. FHM, I: 4
Tolman, R. C. F, I: 3
Torrey, C. C. F, III: 2
Tozzer, A. M. F, III: 2
Trelease, W. F, II: 2
Trevelyan, Sir G. O. FHM, III: 3
Turner, F. J. F, III: 3
Tyler, H. W. F, I: 1
Tyzzer, E. E. F, II: 4
Unwin, W. C. FHM, I: 4
Urban, I. FHM, II: 2
Vallarta, M. S. F, I: 2
Vallée Poussin, C. J. de la. FHM, I: 1
Vaughan, T. W. F, II: 1
Veblen, O. F, I: 1
Verhoeff, F. H. F, II: 4
Vogt, J. H. L. FHM, II: 1
Vries, H. de. FHM, II: 2
Wadsworth, E. A
Wait, W. C. F, III: 1
Walcott, H. P. F, II: 4
Walker, C. H. F, III: 4
Walker, W. H. F, I: 3
Walsh, J. L. F, I: 1
Wambaugh, E. F, III: 1
Ward, R. De C. F, II: 1
Warner, E. P. F, I: 4
Warren, C. H. F, II: 1
Washburn, H. B. F, III: 1
Watson, J. B. F, II: 3
Wearn, J. T. F, II: 4
Webster, D. L. F, I: 2
Webster, E. S. A
Welch, W. H. F, II: 4
Wells, A. E. F, I: 4
Weston, R. S. F, I: 4
Weston, W. H. F, II: 2
Weyl, H. FHM, I: 1
Weysse, A. W. F, II: 3
Wettstein, R. FHM, II: 2

Whatmough, J. F, III: 2
Wheeler, W. M. F, II: 3
White, B. F, II: 4
White, D. F, II: 1
Whitehead, A. N. F, I: 1
Whitlock, H. P. F, II: 1
Whitman, E. A. A
Whitney, W. R. F, I: 3
Wieland, H. FHM, I: 3
Wilkins, E. H. F, III: 2
Williams, F. H. F, II: 4
Williams, R. S. F, I: 3
Willis, B. F, II: 1
Willoughby, W. W. F, III: 3
Wilson, E. B. F, II: 3
Wilson, E. B. F, I: 2
Wilson, E. H. F, II: 2
Wilson, G. G. F, III: 3
Winship, G. P. F, III: 3
Winslow, A. F, II: 1
Wissler, C. F, III: 2
Wister, O. F, III: 4
Wolbach, S. B. F, II: 4
Wolff, J. E. F, II: 1
Wood, H. C. F, II: 4
Wood, R. W. F, I: 2
Woodman, A. G. F, I: 3
Woods, F. A. F, II: 3
Woods, F. S. F, I: 1
Woods, J. H. F, III: 2
Worcester, J. R. F, I: 4
Wright, C. H. C. F, III: 4
Wright, F. E. F, II: 1
Wright, Q. F, III: 1
Yerkes, R. M. F, II: 3
Young, B. L. A
Zeleny, J. F, I: 2
Zinsser, H. F, II: 4

STATUTES AND STANDING VOTES.

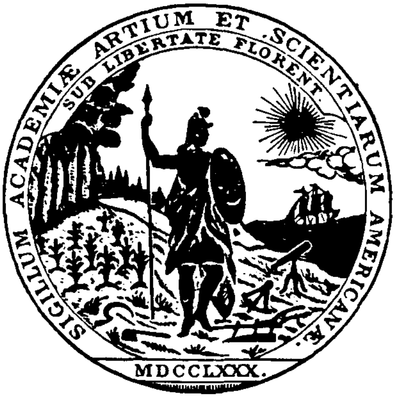
STATUTES.

Adopted November 8, 1911: *amended May* 8, 1912, *January* 8, *and May* 14, 1913, *April* 14, 1915, *April* 12, 1916, *April* 10, 1918, *May* 14, 1919, *February* 8, *April*, 12, *and December* 13, 1922, *February* 14, *March* 14, *and October* 10, 1923, *and March* 10, 1926, *and May* 9, 1928.

CHAPTER I.

THE CORPORATE SEAL.

ARTICLE 1. The Corporate Seal of the Academy shall be as here depicted:


SIGILLUM ACADEMIÆ ARTIUM ET SCIENTIARUM AMERICANÆ
SUB LIBERTATE FLORENT
MDCCLXXX.

ARTICLE 2. The Recording Secretary shall have the custody of the Corporate Seal.

See Chap. v, art. 3; chap. vi, art. 2.

CHAPTER II.

FELLOWS AND FOREIGN HONORARY MEMBERS AND DUES.

ARTICLE 1. The Academy consists of Fellows, who are either citizens or residents of the United States of America, and Foreign Honorary Members. They are arranged in three Classes, according to the Arts and Sciences in which they are severally proficient, and each Class is divided into four Sections, namely:

CLASS I. *The Mathematical and Physical Sciences*

Section 1.	Mathematics and Astronomy
Section 2.	Physics
Section 3.	Chemistry
Section 4.	Technology and Engineering

CLASS II. *The Natural and Physiological Sciences*

Section 1.	Geology, Mineralogy, and Physics of the Globe
Section 2.	Botany
Section 3.	Zoölogy and Physiology
Section 4.	Medicine and Surgery

CLASS III. *The Moral and Political Sciences*

Section 1.	Theology, Philosophy, and Jurisprudence
Section 2.	Philology and Archæology
Section 3.	Political Economy and History
Section 4.	Literature and the Fine Arts

ARTICLE 2. The number of Fellows shall not exceed Six hundred, of whom not more than Four hundred shall be residents of Massachusetts, nor shall there be more than Two hundred and ten in any one Class.

ARTICLE 3. The number of Foreign Honorary Members shall not exceed One hundred. They shall be chosen from among citizens of foreign countries most eminent for their discoveries and attainments in any of the Classes above enumerated. There shall not be more than Thirty-five in any one Class.

ARTICLE 4. If any person, after being notified of his election as Fellow, shall neglect for six months to accept in writing, or, if a Fellow resident within fifty miles of Boston shall neglect to pay his Admission Fee, his election shall be void; and if any Fellow resident within fifty miles of Boston shall neglect to pay his Annual Dues for six months after they are due, provided his attention shall have been called to this Article of the Statutes in the meantime, he shall cease to be a Fellow; but the Council may suspend the provisions of this Article for a reasonable time.

With the previous consent of the Council, the Treasurer may dispense (*sub silentio*) with the payment of the Admission Fee or of the Annual Dues or both whenever he shall deem it advisable. In the case of officers of the Army or Navy who are out of the Commonwealth on duty, payment of the Annual Dues may be waived during such absence if continued during the whole financial year and if notification of such expected absence be sent to the Treasurer. Upon similar notification to the Treasurer, similar exemption may be accorded to Fellows subject to Annual Dues, who may temporarily remove their residence for at least two years to a place more than fifty miles from Boston.

If any person elected a Foreign Honorary Member shall neglect for six months after being notified of his election to accept in writing, his election shall be void.

See Chap. vii, art. 2.

ARTICLE 5. Every Fellow resident within fifty miles of Boston hereafter elected shall pay an Admission Fee of Ten dollars.

Every Fellow resident within fifty miles of Boston shall, and others may, pay such Annual Dues, not exceeding Fifteen dollars, as shall be voted by the Academy at each Annual Meeting, when they shall become due; but any Fellow shall be exempt from the annual payment if, at any time after his admission, he shall pay into the treasury Two hundred dollars in addition to his previous payments. Any Fellow shall also be exempt from Annual Dues who has paid such dues for forty years, or, having attained the age of seventy-five has paid dues for twenty-five years.

All Commutations of the Annual Dues shall be and remain permanently funded, the interest only to be used for current expenses.

Any fellow not previously subject to Annual Dues who takes up his residence within fifty miles of Boston, shall pay to the Treasurer within three months thereafter Annual Dues for the current year, failing which his Fellowship shall cease; but the Council may suspend the provisions of this Article for a reasonable time.

Only Fellows who pay Annual Dues or have commuted them may hold office in the Academy or serve on the Standing Committees or vote at meetings.

ARTICLE 6. Fellows who pay or have commuted the Annual Dues and Foreign Honorary Members shall be entitled to receive gratis one copy of all Publications of the Academy issued after their election.

See Chap. xi, art. 2.

ARTICLE 7. Diplomas signed by the President and the Vice-President of the Class to which the member belongs, and countersigned by the Secretaries, shall be given to Foreign Honorary Members and to Fellows on request.

ARTICLE 8. If, in the opinion of a majority of the entire Council, any Fellow or Foreign Honorary Member shall have rendered himself unworthy of a place in the Academy, the Council shall recommend to the Academy the termination of his membership; and if three-fourths of the Fellows present, out of a total attendance of not less than fifty at a Stated Meeting, or at a Special Meeting called for the purpose, shall adopt this recommendation, his name shall be stricken from the Roll.

See Chap. iii; chap. vi, art. 1; chap. x, art. 1, 7; chap. xi, art. 2.

CHAPTER III.

ELECTION OF FELLOWS AND FOREIGN HONORARY MEMBERS.

The procedure in the election of Fellows and Foreign Honorary Members shall be as follows:

Nominations to Fellowship or Foreign Honorary Membership in any Section must be signed by two Fellows of that Section, or by three Fellows of any Sections, and sent to the Corresponding Secretary accompanied by a statement of the qualifications of the nominee and brief biographical data.

Notice shall be sent to every Fellow not later than the fifteenth of January in each year, reminding him that all nominations must be in the hands of the Corresponding Secretary before the fifteenth of February following.

A list of the nominees, giving a brief account of each, with the names of the nominators, shall be sent to every Fellow with a request that he return the list with such confidential comments and indications of preference as he may choose to make.

All the nominations, with any comments thereon and with expressions of preference on the part of the Fellows, shall be referred to the appropriate Class Committees, which shall canvass them, and report their recommendations in writing to the Council before the Stated Meeting of the Academy in April.

Elections of Fellows and Foreign Honorary Members shall be made by the Council before the Annual Meeting in May, and announced at that meeting.

Persons nominated in any year, but not elected, may be carried over to the list of nominees for the next year at the discretion of the Council, but shall not be further continued unless renominated.

See Chap. ii; chap. vi, art. 1; chap. x, art. 1.

CHAPTER IV.

OFFICERS.

ARTICLE 1. The Officers of the Academy shall be a President (who shall be Chairman of the Council), three Vice-Presidents (one from each Class), a Corresponding Secretary (who shall be Secretary of the Council), a Recording Secretary, a Treasurer, a Librarian, and an Editor, all of whom shall be elected by ballot at the Annual Meeting, and shall hold their respective offices for one year, and until others are duly chosen and installed.

There shall be also twelve Councillors, one from each Section of each Class. At each Annual Meeting three Councillors, one from each Class, shall be elected by ballot to serve for the full term of four years and until others are duly chosen and installed. The same Fellow shall not be eligible for two successive terms.

The Councillors, with the other officers previously named, and the Chairman of the House Committee, *ex officio*, shall constitute the Council.

See Chap. xi, art. 1.

Article 2. If any officer be unable, through death, absence, or disability, to fulfil the duties of his office, or if he shall resign, his place may be filled by the Council in its discretion for any part or the whole of the unexpired term.

Article 3. At the Stated Meeting in March, the President shall appoint a Nominating Committee of Three Fellows having the right to vote, one from each Class. This Committee shall prepare a list of nominees for the several offices to be filled, and for the Standing Committees, and file it with the Recording Secretary not later than four weeks before the Annual Meeting.

See Chap. vi, art. 2.

Article 4. Independent nominations for any office, if signed by at least twenty Fellows having the right to vote, and received by the Recording Secretary not less than ten days before the Annual Meeting, shall be inserted in the call therefor, and shall be mailed to all the Fellows having the right to vote.

See Chap. vi, art. 2.

Article 5. The Recording Secretary shall prepare for use in voting at the Annual Meeting a ballot containing the names of all persons duly nominated for office.

CHAPTER V.

The President.

Article 1. The President, or in his absence the senior Vice-President present (seniority to be determined by length of continuous fellowship in the Academy), shall preside at all meetings of the Academy. In the absence of all these officers, a Chairman of the meeting shall be chosen by ballot.

Article 2. Unless otherwise ordered, all Committees which are not elected by ballot shall be appointed by the presiding officer.

ARTICLE 3. Any deed or writing to which the Corporate Seal is to be affixed, except leases of real estate, shall be executed in the name of the Academy by the President or, in the event of his death, absence, or inability, by one of the Vice-Presidents, when thereto duly authorized.

See Chap. ii, art. 7; chap. iv, art. 1, 3; chap. vi, art. 2; chap. vii, art. 1; chap. x, art. 6; chap. xi, art. 1, 2; chap. xii, art. 1.

CHAPTER VI.

THE SECRETARIES.

ARTICLE 1. The Corresponding Secretary shall conduct the correspondence of the Academy and of the Council, recording or making an entry of all letters written in its name, and preserving for the files all official papers which may be received. At each meeting of the Council he shall present the communications addressed to the Academy which have been received since the previous meeting, and at the next meeting of the Academy he shall present such as the Council may determine.

He shall notify all persons who may be elected Fellows or Foreign Honorary Members, send to each a copy of the Statutes, and on their acceptance issue the proper Diploma. He shall also notify all meetings of the Council; and in case of the death, absence, or inability of the Recording Secretary he shall notify all meetings of the Academy.

Under the direction of the Council, he shall keep a List of the Fellows and Foreign Honorary Members, arranged in their several Classes and Sections. It shall be printed annually and issued as of the first day of July.

See Chap. ii, art. 7; chap. iii, art. 2, 3; chap. iv, art. 1; chap. x, art. 6; chap. xi, art. 1; chap. xii, art. 1.

ARTICLE 2. The Recording Secretary shall have the custody of the Charter, Corporate Seal, Archives, Statute-Book, Journals, and all literary papers belonging to the Academy.

Fellows borrowing such papers or documents shall receipt for them to their custodian.

The Recording Secretary shall attend the meetings of the Academy and keep a faithful record of the proceedings with the names of the Fellows present; and after each meeting is duly opened, he shall read the record of the preceding meeting.

He shall notify the meetings of the Academy to each Fellow and by mail at least seven days beforehand, and in his discretion may also cause the meetings to be advertised; he shall apprise Officers and Committees of their election or appointment, and inform the Treasurer of appropriations of money voted by the Academy.

After all elections, he shall insert in the Records the names of the Fellows by whom the successful nominees were proposed.

He shall send the Report of the Nominating Committee in print to every Fellow having the right to vote at least three weeks before the Annual Meeting.

See Chap. iv, art. 3.

In the absence of the President and of the Vice-Presidents he shall, if present, call the meeting to order, and preside until a Chairman is chosen.

See Chap. i; chap. ii, art. 7; chap. iv, art. 3, 4, 5; chap. x, art. 6; chap. xi, art. 1, 2; chap. xii, art. 1, 3.

ARTICLE 3. The Secretaries, with the Editor, shall have authority to publish such of the records of the meetings of the Academy as may seem to them likely to promote its interests.

CHAPTER VII.

THE TREASURER AND THE TREASURY.

ARTICLE 1. The Treasurer shall collect all money due or payable to the Academy, and all gifts and bequests made to it. He shall pay all bills due by the Academy, when approved by the proper officers, except those of the Treasurer's office, which may be paid without such approval; in the name of the Academy he shall sign all leases of real estate; and, with the written consent of a member of the Committee on Finance, he shall make all transfers of stocks, bonds, and other securities belonging to the Academy, all of which shall be in his official custody.

He shall keep a faithful account of all receipts and expenditures, submit his accounts annually to the Auditing Committee, and render them at the expiration of his term of office, or whenever required to do so by the Academy or the Council.

He shall keep separate accounts of the income of the Rumford Fund, and of all other special Funds, and of the appropriation thereof, and render them annually.

His accounts shall always be open to the inspection of the Council.

ARTICLE 2. He shall report annually to the Council at its March meeting on the expected income of the various Funds and from all other sources during the ensuing financial year. He shall also report the names of all Fellows who may be then delinquent in the payment of their Annual Dues.

ARTICLE 3. He shall give such security for the trust reposed in him as the Academy may require.

ARTICLE 4. With the approval of a majority of the Committee on Finance, he may appoint an Assistant Treasurer to perform his duties, for whose acts, as such assistant, he shall be responsible; or, with like approval and responsibility, he may employ any Trust Company doing business in Boston as his agent for the same purpose, the compensation of such Assistant Treasurer or agent to be fixed by the Committee on Finance and paid from the Funds of the Academy.

ARTICLE 5. At the Annual Meeting he shall report in print all his official doings for the preceding year, stating the amount and condition of all the property of the Academy entrusted to him, and the character of the investments.

ARTICLE 6. The Financial Year of the Academy shall begin with the first day of April.

ARTICLE 7. No person or committee shall incur any debt or liability in the name of the Academy, unless in accordance with a previous vote and appropriation therefor by the Academy or the Council, or sell or otherwise dispose of any property of the Academy, except cash or invested funds, without previous consent and approval of the Council.

See Chap. ii, art. 4, 5; chap. vi, art. 2; chap. x, art. 6; chap. xi, art. 1, 2, 3; chap. xii, art. 1.

CHAPTER VIII.

THE LIBRARIAN AND THE LIBRARY.

ARTICLE 1. The Librarian shall have charge of the printed books, keep a correct catalogue thereof, and provide for their delivery from the Library.

At the Annual Meeting, as Chairman of the Committee on the Library, he shall make a Report on its condition.

ARTICLE 2. In conjunction with the Committee on the Library he shall have authority to expend such sums as may be appropriated by the Academy for the purchase of books, periodicals, etc., and for defraying other necessary expenses connected with the Library.

ARTICLE 3. All books procured from the income of the Rumford Fund or of other special Funds shall contain a book-plate expressing the fact.

ARTICLE 4. Books taken from the Library shall be receipted for to the Librarian or his assistant.

ARTICLE 5. Books shall be returned in good order, regard being had to necessary wear with good usage. If any book shall be lost or injured, the Fellow to whom it stands charged shall replace it by a new volume or by a new set, if it belongs to a set, or pay the current price thereof to the Librarian, whereupon the remainder of the set, if any, shall be delivered to the Fellow so paying, unless such remainder be valuable by reason of association.

ARTICLE 6. All books shall be returned to the Library for examination at least one week before the Annual Meeting.

ARTICLE 7. The Librarian shall have the custody of the Publications of the Academy. With the advice and consent of the President, he may effect exchanges with other associations.

See Chap. ii, art. 6; chap. xi, art. 1, 2.

CHAPTER IX.

THE EDITOR AND THE PUBLICATIONS.

ARTICLE 1. The Editor shall have charge of the conduct through the press of the Proceedings and the Memoirs, and all correspondence relative thereto, and shall have power to fix the price at which individual numbers of the Proceedings and Memoirs are sold.

ARTICLE 2. In conjunction with the Committee of Publication, he shall have authority to expend such sums as may be appropriated by the Academy for printing the publications and for defraying other expenses therewith connected.

ARTICLE 3. All publications which are financed in whole or in part from the income of the Rumford Fund or from the income of other special funds, and all publications of work done with the aid of the Rumford Fund or other special funds, shall contain a conspicuous statement of this fact.

ARTICLE 4. Two hundred extra copies of each paper printed in the Proceedings or Memoirs shall be placed at the disposal of the author without charge.

If, on account of the number of communications offered for publication, it shall be necessary to decline for publication communications otherwise acceptable, members of the Academy shall be given preference in each of the several Classes over non-members; but whenever it shall be necessary to exercise this preference, the Editor shall inform the Council of the fact.

See Chap. iv, art. 1; chap. vi, art. 3; chap. x, art. 6; chap. xi, art. 4.

CHAPTER X.

THE COUNCIL.

ARTICLE 1. The Council shall exercise a discreet supervision over all nominations and elections to membership, and in general supervise all the affairs of the Academy not explicitly reserved to the Academy as a whole or entrusted by it or by the Statutes to standing or special committees.

It shall consider all nominations duly sent to it by any Class Committee, and act upon them in accordance with the provisions of Chapter III.

With the consent of the Fellow interested, it shall have power to make transfers between the several Sections, reporting its action to the Academy.

See Chap. iii, art. 2, 3; chap. xi, art. 1.

ARTICLE 2. Seven members shall constitute a quorum.

ARTICLE 3. It shall establish rules and regulations for the transaction of its business, and provide all printed and engraved blanks and books of record.

ARTICLE 4. It shall act upon all resignations of officers, and all resignations and forfeitures of Fellowship; and cause the Statutes to be faithfully executed.

It shall appoint all agents and subordinates not otherwise provided for by the Statutes, prescribe their duties, and fix their compensation. They shall hold their respective positions during the pleasure of the Council.

ARTICLE 5. It may appoint, for terms not exceeding one year, and prescribe the functions of, such committees of its number, or of the Fellows of the Academy, as it may deem expedient, to facilitate the administration of the affairs of the Academy or to promote its interests.

ARTICLE 6. At its March meeting it shall receive reports from the President, the Secretaries, the Treasurer, and the Standing Committees, on the appropriations severally needed for the ensuing financial year. At the same meeting the Treasurer shall report on the expected income of the various Funds and from all other sources during the same year.

A report from the Council shall be submitted to the Academy, for action, at the March meeting, recommending the appropriation which in the opinion of the Council should be made.

On the recommendation of the Council, special appropriations may be made at any Stated Meeting of the Academy, or at a Special Meeting called for the purpose.

See Chap. xi, art. 3.

Article 7. After the death of a Fellow or Foreign Honorary Member, it shall appoint a member of the Academy to prepare a biographical notice for publication in the Proceedings.

Article 8. It shall report at every meeting of the Academy such business as it may deem advisable to present.

See Chap. ii, art. 4, 5, 8; chap. iv, art. 1, 2; chap. vi, art. 1; chap. vii, art. 1; chap. xii, art. 1, 4.

CHAPTER XI.

Standing Committees.

Article 1. The Class Committee of each Class shall consist of the Vice-President, who shall be chairman, and the four Councillors of the Class, together with such other officer or officers annually elected as may belong to the Class. It shall consider nominations to Fellowship in its own Class, and report in writing to the Council such as may receive at a Class Committee Meeting a majority of the votes cast, provided at least three shall have been in the affirmative.

See Chap. iii, art. 2.

Article 2. At the Annual Meeting the following Standing Committees shall be elected by ballot to serve for the ensuing year:

(i) *The Committee on Finance*, to consist of three Fellows, who, through the Treasurer, shall have full control and management of the funds and trusts of the Academy, with the power of investing the funds and changing the investments thereof in their discretion.

See Chap. iv, art. 3; chap. vii, art. 1, 4; chap. x, art. 6.

(ii) *The Rumford Committee*, to consist of seven Fellows, who shall report to the Academy on all applications and claims for the Rumford Premium. It alone shall authorize the purchase of books, publications and apparatus at the charge of the income from the Rumford Fund, and generally shall see to the proper execution of the trust.

See Chap. iv, art. 3; chap. x, art. 6.

(iii) *The Cyrus Moors Warren Committee*, to consist of seven Fellows, who shall consider all applications for appropriations from the income of the Cyrus Moors Warren Fund, and generally shall see to the proper execution of the trust.

See Chap. iv, art. 3; chap. x, art. 6.

(iv) *The Committee of Publication*, to consist of the Editor, *ex officio*, as Chairman, and three other Fellows, one from each Class, to whom all communications submitted to the Academy for publication shall be referred, and to whom the printing of the Proceedings and the Memoirs shall be entrusted.

It shall fix the price at which volumes of the publications shall be sold; but Fellows may be supplied at half price with volumes which may be needed to complete their sets, but which they are not entitled to receive gratis.

It shall determine when the pressure of material offered for publication makes it necessary to give preference to members of the Academy as compared with non-members, or to give priority to certain members as compared with others, and to what extent this preference or priority shall be applied in each of the three Classes, to the end that a proper balance of the facilities of publication with respect to subject matter and authors may be maintained.

See Chap. iv, art. 3; chap. vi, art. 1, 3; chap. ix; chap. x, art. 6.

(v) *The Committee on the Library*, to consist of the Librarian, *ex officio*, as Chairman, and three other Fellows, one from each Class, who shall examine the Library and make an annual report on its condition and management.

See Chap. iv, art. 3; chap. viii, art. 1, 2; chap. x, art. 6.

(vi) *The House Committee*, to consist of three Fellows, who shall have charge of all expenses connected with the House, including the general expenses of the Academy not specifically assigned to the care of other Committees or Officers.

See Chap. iv, art. 1, 3; chap. x, art. 6.

(vii) *The Committee on Meetings*, to consist of the President, the Recording Secretary, and three other Fellows, who shall have charge of plans for meetings of the Academy.

See Chap. iv, art. 3; chap. x, art. 6.

(viii) *The Auditing Committee,* to consist of two Fellows, who shall audit the accounts of the Treasurer, with power to employ an expert and to approve his bill.

See Chap. iv, art. 3; chap. vii, art. 1; chap. x, art. 6.

ARTICLE 3. The Standing Committees shall report annually to the Council in March on the appropriations severally needed for the ensuing financial year; and all bills incurred on account of these Committees, within the limits of the several appropriations made by the Academy, shall be approved by their respective Chairmen.

In the absence of the Chairman of any Committee, bills may be approved by any member of the Committee whom he shall designate for the purpose.

See Chap. vii, art. 1, 7; chap. x, art. 6.

CHAPTER XII.

MEETINGS, COMMUNICATIONS, AND AMENDMENTS.

ARTICLE 1. There shall be annually eight Stated Meetings of the Academy, namely, on the second Wednesday of October, November, December, January, February, March, April, and May. Only at these meetings, or at adjournments thereof regularly notified, or at Special Meetings called for the purpose, shall appropriations of money be made or amendments of the Statutes or Standing Votes be effected.

The Stated Meeting in May shall be the Annual Meeting of the Corporation.

Special Meetings shall be called by either of the Secretaries at the request of the President, of a Vice-President, of the Council, or of ten Fellows having the right to vote; and notifications thereof shall state the purpose for which the meeting is called.

A meeting for receiving and discussing literary or scientific communications may be held on the fourth Wednesday of each month, excepting July, August, and September; but no business shall be transacted at said meetings.

ARTICLE 2. Twenty Fellows having the right to vote shall constitute a quorum for the transaction of business at Stated or Special

Meetings. Fifteen Fellows shall be sufficient to constitute a meeting for literary or scientific communications and discussions.

ARTICLE 3. Upon the request of the presiding officer or the Recording Secretary, any motion or resolution offered at any meeting shall be submitted in writing.

ARTICLE 4. No report of any paper presented at a meeting of the Academy shall be published by any Fellow without the consent of the author; and no report shall in any case be published by any Fellow in a newspaper as an account of the proceedings of the Academy without the previous consent and approval of the Council. The Council, in its discretion, by a duly recorded vote, may delegate its authority in this regard to one or more of its members.

ARTICLE 5. No Fellow shall introduce a guest at any meeting of the Academy until after the business has been transacted, and especially until after the result of the balloting upon nominations has been declared.

ARTICLE 6. The Academy shall not express its judgment on literary or scientific memoirs or performances submitted to it, or included in its Publications.

ARTICLE 7. All proposed Amendments of the Statutes shall be referred to a committee, and on its report, at a subsequent Stated Meeting or at a Special Meeting called for the purpose, two-thirds of the ballot cast, and not less than twenty, must be affirmative to effect enactment.

ARTICLE 8. Standing Votes may be passed, amended, or rescinded at a Stated Meeting, or at a Special Meeting called for the purpose, by a vote of two-thirds of the members present. They may be suspended by a unanimous vote.

See Chap. ii, art. 5, 8; chap. iii; chap. iv, art. 3, 4, 5; chap. v, art. 1; chap. vi, art. 1, 2; chap. x, art. 8.

STANDING VOTES.

1. Communications of which notice has been given to either of the Secretaries shall take precedence of those not so notified.

2. Fellows may take from the Library six volumes at any one time, and may retain them for three months, and no longer. Upon special application, and for adequate reasons assigned, the Librarian may permit a larger number of volumes, not exceeding twelve, to be drawn from the Library for a limited period.

3. Works published in numbers, when unbound, shall not be taken from the Hall of the Academy without the leave of the Librarian.

4. The Council, under such rules respecting nominations as it may prescribe, may elect as Associates of the Academy a limited number of men of mark in affairs or of distinguished service in the community.

Associates shall be entitled to the same privileges as Fellows, but shall not have the right to vote.

The admission fee and annual dues of Associates shall be the same as those of Fellows residing within fifty miles of Boston.

5. Communications offered for publication in the Proceedings or Memoirs of the Academy shall not be accepted for publication before the author shall have informed the Committee on Meetings of his readiness, either himself or through some agent, to use such time as the Committee may assign him at such meeting as may be convenient both to him and to the Committee, for the purpose of presenting to the Academy a general statement of the nature and significance of the results contained in his communication.

RUMFORD PREMIUM.

In conformity with the terms of the gift of Sir Benjamin Thompson, Count Rumford, of a certain Fund to the American Academy of Arts and Sciences, and with a decree of the Supreme Judicial Court of Massachusetts for carrying into effect the general charitable intent and purpose of Count Rumford, as expressed in his letter of gift, the Academy is empowered to make from the income of the Rumford Fund, as it now exists, at any Annual Meeting, an award of a gold and a silver medal, being together of the intrinsic value of three hundred dollars, as a Premium to the author of any important discovery or useful improvement in light or heat, which shall have been made and published by printing, or in any way made known to the public, in any part of the continent of America, or any of the American islands; preference always being given to such discoveries as, in the opinion of the Academy, shall tend most to promote the good of mankind; and, if the Academy sees fit, to add to such medals, as a further Premium for such discovery and improvement, a sum of money not exceeding three hundred dollars.

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